

JOURNAL

OF THE

AMERICAN WATER WORKS ASSOCIATION

VOL. 27

MAY, 1935

No. 5

CONTENTS

Final Report of the Committee on Uniform Marking of Fire Hydrants.....	551
Uniform Marking of Fire Hydrants. By F. C. Jordan....	553
The Spectrographic Determination of Minor Chemical Constituents in Various Water Supplies in the United States. By Mathew M. Braidech and F. H. Emery..	557
Search for Underground Water in Perpetually Frozen Areas. By M. J. Chernyshoff.....	581
Hydrographic and Meteorological Surveys for Water Supply. By James E. Jones and George A. Lewis.....	594
Elimination of Pits and Subground-Level Pumprooms. By O. E. Brownell.....	600
Danger of Contamination of Water Supply When Water and Sewer Pipes are Close Together. By O. E. Brownell.....	606
Mechanical Cleaning of Water Mains at Evansville, Indiana. By Charles Streithof.....	610
Water Supply for Construction Camps. By Clayburn C. Elder.....	613
Corrosion from Zero Softened Waters. By Ray L. Derby..	627
Practical Aspects of Coagulation with Ferric Chloride. By Charles Gilman Hyde.....	631
A Request for Information on Ground Water Replenishment.....	662
Erratum.....	664
Abstracts.....	665

All correspondence relating to the publication of papers should be addressed to the editor, Abel Wolman, 2411 North Charles Street, Baltimore, Maryland.

Because of the necessity for rigid economy, no reprints of articles will be furnished to contributors free of charge. Reprints may be purchased at the usual prices.

• • FAMOUS VICTIMS OF WATER BORNE DISEASES



LOST to the WORLD OF LETTERS —HEGEL, *Great Rationalist*

HAILED as Aristotle's only rival in the field of logic, Hegel, German Philosopher, fell a victim of cholera—a water borne disease—in 1831. His tenet of philosophy—the application of past experience in solving present problems—would admit no such calamity today. No more need the spectre of water borne disease stalk drinking water supplies—when CHLORINATION'S ready protection offers a constant guard.

W&T Visible Vacuum Chlorinators take the guesswork out of that protection. Years of experience show their complete reliability, low maintenance cost and simplicity of operation.

When the cost of chlorination is so low—less than a penny per person per year—it takes no feat of logic to deduce the fact that every water supply deserves this same protection—a positive safeguard, when W&T Visible Vacuum Chlorinators are used.

The tenet of modern public health practice is "The Only Safe Water is a Sterilized Water."

Technical Publications 38, 157 and 158 describing W&T Visible Vacuum Chlorinators are yours for the asking.

WALLACE & TIERNAN CO., Inc.

Manufacturers of Chlorine and Ammonia Control Apparatus
NEWARK, NEW JERSEY Branches in



Principal Cities...Main Factory, Belleville, N. J.



JOURNAL
OF THE
AMERICAN WATER WORKS ASSOCIATION

The Association is not responsible, as a body, for the facts and opinions
advanced in any of the papers or discussions published in its proceedings
Discussion of all papers is invited

Vol. 27

MAY, 1935

No. 5

FINAL REPORT OF THE COMMITTEE ON UNIFORM
MARKING OF FIRE HYDRANTS¹

To the Officers and Members of the American Water Works Association:

Your Committee on Uniform Marking of Fire Hydrants have considered the data at hand on the subject.

It has been impossible for the committee to meet on account of the scattered location of its members and this report is the result of limited correspondence.

We believe that the idea of indicating relative available fire service draft of hydrants by different colors is of substantial value to Water and Fire Depts. While we agree that tests of individual hydrants do not give as complete and satisfactory results as group testing, we feel that such a test has sufficient value to make it worthy of adoption as a start in the right direction.

We therefore recommend:

(a) That hydrants be classified as follows:

Class A—Flow capacity of 1000 g.p.m. or greater

Class B—Flow capacity of 500–1000 g.p.m.

Class C—Flow capacity of less than 500 g.p.m.

Capacities to be rated by pitometer tests of individual hydrants at a period of ordinary demand. Rating to be based on 20 pounds

¹This report has not yet been approved by the Committee on Water Works Practice. It is printed here for discussion by the members of the Association.—EDITOR.

per square inch residual pressure when initial pressures are over 40 pounds per square inch. When initial pressures are less than 40 pounds per square inch residual pressures shall be at least half of the initial.

(b) That the following capacity-indicating color scheme be adopted as providing simplicity and consistency with colors used in signal work for safety, danger and intermediate condition;

Public Hydrants:

All barrels to be chrome yellow, except in cases where another color has already been adopted.

Class A—Tops and nozzle caps—Green

Class B—Tops and nozzle caps—Orange

Class C—Tops and nozzle caps—Red

Private Hydrants:

Within private enclosures, the marking to be at the discretion of the owners.

When in public streets, they should be painted entirely red to distinguish them from public hydrants.

(c) That all location markers for flush hydrants should carry the same color background as stated above for class indication, with such data stencilled or painted thereon as may be deemed necessary.

(d) That the colors shall be understood to signify only the individual capacity of the hydrant as tested and not group hydrant effect.

WM. W. BRUSH,

R. L. DOBBIN,

H. E. HALPIN,

GEO. W. PRACY,

S. H. TAYLOR, *chairman.*

DISCUSSION OF REPORT ON "UNIFORM MARKING OF FIRE HYDRANTS"

BY F. C. JORDAN

(Indianapolis Water Company, Indianapolis, Ind.)

For several years various associations interested in public and private fire protection service have given thought to the proposed Uniform Marking of Fire Hydrants and a committee appointed by the American Water Works Association has submitted a tentative report, which report is printed in this issue of the JOURNAL.

In order that this discussion might present something of value, I held several conferences with ten or twelve of Indiana's fire protection and fire prevention authorities and the thoughts which are now presented represent the views of these men based on several hours of careful consideration of this subject.

At the outset I desire to say that all of the men present at our conferences are sympathetic to the general idea of hydrant testing and are wholeheartedly in favor of any plan which will increase the efficiency of the public and private fire protection service. They are wholeheartedly in favor of a careful study of the distribution maps and believe that every fire and water department should be thoroughly conversant with the location and sizes of all mains and hydrants and the quantity of water available for fire protection service at given locations. They are likewise wholeheartedly in favor of 100 percent coöperation between the fire and water departments to the end that efficient fire service may be rendered and property safeguarded.

It is our thought that this suggested uniform marking of fire hydrants is of more importance to the smaller town where outside aid is needed at the time of threatened conflagration than it is to the larger towns, and we do not want to see any standard adopted which will in any way be detrimental to the fire protection interests in the larger cities. Many of the leading cities with adequate water supplies paint their hydrants yellow—the best color for visibility, but under the suggested plan of hydrant marking yellow hydrants will be classed as sub-standard, or Class B hydrants. In other words,

the best color for visibility will apparently be lost to us if this standard is adopted.

One of the fire chiefs who spent several hours in a consideration of the subject asked the pointed question: "Why do we have Class C hydrants?" namely the hydrants with a fire flow of less than 500 gallons per minute.

Paragraph 31, page 32, of the "Blue Book" of the National Board of Fire Underwriters reads in part as follows:

Hydrants shall be able to deliver 600 gallons per minute with a loss of not more than $2\frac{1}{2}$ pounds in the hydrant and a total loss of not more than 5 pounds between the street main and outlet; they shall have not less than two $2\frac{1}{2}$ -inch outlets and also a large suction connection where engine service is necessary.

It would seem from this standard requirement which has been in force for several years that a so-called fire hydrant which has an available fire flow of less than 500 gallons per minute does not merit the name of standard fire hydrant.

One of the fire chiefs present at the conferences in my office voiced the following plea:

Please paint the fire hydrants the very best color for visibility—namely, yellow, and do not place upon us the burden of running up and down some street at night to locate some hydrant which does not carry a stop or caution marking.

In further comment, this fire chief stated:

One of the outstanding rules of our operation is—Get to the fire as soon as possible; connect to the nearest fire hydrant and go to work, and any plan which interferes with this program will in my opinion place a serious handicap on our fire fighting.

As early as 1911 Messrs. Metcalf, Kuichling and Hawley presented before the American Water Works Association an invaluable treatise on public fire protection service and recommended some method of credit or payment for fire service based upon the amount of water available through the mains and fire hydrants, it being their thought that such a basis of credit or payment would encourage the installation of adequate sized mains and hydrants and would eventually do away with the small main and hydrant which was even then fast becoming outlawed through the introduction of the large capacity fire pumper.

In a discussion of this remarkable paper Mr. John W. Alvord, then President of the American Water Works Association, said in part:

It has occurred to me to suggest what I might call a graduated hydrant rental based on the value of the hydrant as fire protection with regard also

to the property which that particular hydrant would protect; taking the hydrant rental as a whole and reapportioning it among the hydrants. The thought has occurred to me in this connection of adjusting it on some such basis as the size of the pipe or main from which it feeds.

In an enlargement of this theory, Mr. Alvord in 1914 recommended the adoption of the "Inch-foot Basis" under which plan the credit or payment for public fire protection service is based on the carrying capacity of the water mains, with a nominal charge for each fire hydrant connected therewith. In stating the advantages of such an arrangement Mr. Alvord said in part:

Under this plan there is every incentive to the company in extending its distribution system to keep sizes of mains up to the fire requirements and to reinforce weak districts and the city's interest in fire protection and the company's interest in proper remuneration are thus co-ordinate.

Under this comprehensive plan the public and private fire protection service in many cities of the country has been materially improved and the low flow hydrant is gradually being replaced with hydrants of large volume. It is an unfortunate fact, however, that many cities throughout the country have not adopted the inch-foot basis and are still taking credit or receiving pay on the "per-hydrant basis," which basis gives little or no incentive for increasing the fire defenses insofar as the available water supply is concerned. In respect to some such basis for credit or payment for fire protection service there is no essential difference between the publicly owned or privately owned water plant. In either plant credit is being taken or pay is being received for fire service and the inch-foot basis apparently gives the best measure of the value of that service.

It has been stated that the average fire chief a fire hydrant is a fire hydrant and in my studies of the subject I have about reached the conclusion that the fire chief has a right to expect a reasonably adequate fire flow from each hydrant in his section. In other words, he has a right to feel that he will find at each fire hydrant an adequate supply of water for his fire fighting apparatus whether that apparatus be of old vintage with small capacity, or of latest type with large capacity. That very feeling places upon the fire chief the responsibility of coöperating with the water plant superintendent in every effort to increase the efficiency of the fire service available through the distribution system.

In a rather extensive correspondence on the subject I find that some of the water plants in the eastern states where the proposed uni-

form marking originated are not entirely sold on the colors suggested and prefer to use some color scheme other than the one outlined. In the course of the discussions in my office one of the men suggested that if we are to adopt some color scheme to be operative until such time as the fire protection service is built up to standard requirements we might paint all large flow Class A hydrants yellow; Class B hydrants blue or green, and Class C hydrants red.

If such a plan is adopted we then face the question as to who is to make the fire flow tests and do the necessary painting, and the further question as to whether this work will be done in the average sized town unless some persuasive authority such as the National Board of Fire Underwriters shoulders the responsibility of carrying the plan through to its successful conclusion.

One of the engineering authorities suggested that the fire flows should be made by the fire chief or other member of the fire department and that the fire chief should report to the proper authorities all cases of deficient flow which he found while making the flow test, together with his recommendations looking to the correction of these deficiencies.

It is exceedingly fortunate that the spot light of publicity is being turned on the public fire hydrants and I hope that these studies will continue until we have adopted some plan under which every fire hydrant throughout the country will have been tested, the weak spots located, and steps taken to correct these deficiencies. The great objective of increased fire protection service will be better advanced, however, through the adoption and carrying out of the inch-foot plan, or other similar workable plan, which will cause the American public to understand that the low flow hydrant does not belong in the American picture of today. Would it not be better for us to turn our attention to the increasing of the fire flows so that we may give adequate protection rather than to the marking of hydrants to denote the shortcomings.

Carrying out this thought, let me urge that every water plant superintendent and fire chief coöperate in making a careful study of the distribution system; make fire flow tests, especially in the higher value districts where outside aid may be used, and install those large feeder mains and hydrants which will make possible that adequate service which is the city's only safeguard against large fire loss.

(Presented before the Indiana Section meeting, March 8, 1935.)

THE SPECTROGRAPHIC DETERMINATION OF MINOR
CHEMICAL CONSTITUENTS IN VARIOUS WATER
SUPPLIES IN THE UNITED STATES

BY MATHEW M. BRAIDECHE

(*Senior Chemist, Baldwin Filtration Plant, Department of Public
Utilities, Cleveland, O.*)

AND

F. H. EMERY

(*Spectrographer, National Smelting Company, Cleveland, O.*)

This paper is based upon the experience derived from the experimental work conducted in Cleveland¹ on the utilization of "aluminum dross-fines" as a source of raw material for the manufacture of aluminum sulphate in syrup form. This material being a waste by-product, arising out of the remelting of scrap and waste aluminum in the secondary-aluminum industry, our attention was drawn to the possibility of the introduction of mineral impurities into the water supply coagulated with the use of such a syrup. It was pointed out that using these "dross-fines" for the production of this material, various metallic impurities arising from the alloying constituents originally present in the scraps, i.e., copper, lead, magnesium, manganese, nickel, tin, zinc, etc., may be encountered to a much greater extent than would be the case with bauxite or other aluminum minerals.

One of the questions brought out in particular, was that regarding the fluorine compounds resulting from the use of fluxes containing fluorine salts, and their possible presence in the syrup manufactured from these reclaimed fines. It was, therefore, very important that some definite understanding be made regarding these, to preclude the possibilities of any deleterious or injurious consequences upon public health.

In order to thoroughly check this matter, recourse was made to the facilities for spectrographic analysis extended by the laboratories of the National Smelting Company, since the detection and estimation

of minute traces of metallic impurities are tedious and troublesome, and quite outside the province of the ordinary water works laboratory.

The series of spectrographic examinations of the treated waters that followed were productive of much interesting and enlightening information on the unexpected and unsuspected presence of a large number of chemical elements. The soundness and the simplicity of this type of testing, immediately inspired a desire to extend the range of our knowledge regarding the minor and less familiar "trace elements" not commonly associated with drinking water supplies; a field that has, so far, been, more or less, closed. After some thought on the matter, a preliminary survey of a selected group of different water supplies, from various municipalities throughout the State, was conducted with the coöperation of the State Department of Health. The recounting of the data obtained in a paper presented to the recent Ohio Conference on Water Purification,² encouraged a request for a similar survey of various typical water supplies in the United States, and the preparation of a paper on the accumulated data, with a brief account of the underlying principles of spectrographic analysis, for report to the New York Meeting of The Association.

THE FUNDAMENTAL PRINCIPLES OF SPECTROGRAPHIC ANALYSIS

Due to the recent advances being made in every direction, the spectrograph is gradually changing from a kind of a "visionary" and a scientific curiosity to one of the most practical and accurate tools to be placed into the hands of a chemist. Today, it is rapidly gaining recognition and wide application in a large number of varied industrial processes as a device which extends the range of accurate analysis to limits previously unattainable.

The spectrograph offers a most searching and extremely delicate method for qualitative analysis. It is capable of a high order of sensitivity without interference of other substances. It offers the most nearly infallible method for accurate qualitative data, which is also semi-quantitative, on complicated mixtures impossible to test or check by ordinary chemical methods. Furthermore, it is a micro-method, more popularly called the "speck" test; as one can work with minute traces of the material. A fraction of a milligram answers all requirements, with quantities much smaller than would be required in micro-chemical apparatus and yet obtain accurate reproducible results. This test method is particularly serviceable as a "shot gun" method, since a complete analysis is effected, revealing without special

effort and anticipation the whole of its components—including any accidental or unsuspected impurities, as it does not discriminate between that which is specifically looked for and that which is wholly out of mind. For example, few would suspect the presence of silver, arsenic, boron, chromium, tin, and nickel, in a natural water, yet they have been found to be rare and occasional constituents of some water supplies.

The detection of extremely minute traces of some chemicals by the usual chemical procedures, like fluorine³ in water, for example, is tedious and, more or less, difficult. As a matter of fact, the presence of fluorides in water coming from areas where the dental effect known as "mottled enamel" was endemic, was first revealed by Churchill and Petrey⁴ by means of a spectrograph—which is but one indication of the inestimable value of this type of testing.

This remarkable sensitiveness and the rapidity with which many of the chemical elements may be detected remains unrivaled. The limiting quantities, or "minima," which are capable of detection, are extraordinarily small. The absolute order of magnitude of these limiting quantities varies greatly with the different elements and their state of chemical combination, as well as with the conditions of test. Some of the elements, including magnesium, copper, silver, and beryllium, are exceedingly sensitive and may readily be detected when present in amounts in the fifth, or even in the sixth, decimal place of percentage. Most of the other elements are easily detected and estimated in the third and fourth decimal figure. The non-metals, in general, do not yield definite indications, using the ordinary arc and spark method of excitation, although some of the intermediate elements, like arsenic, selenium and tellurium are detectable at moderately high concentrations. Silicon resembles the metals in giving a strong spectrum, even at quite low concentrations.

One recent authority⁵ attempts to give the following "minima" for some of the more common elements—one three-millionth of a milligram of sodium, one one-hundred-thousandth of a milligram of lithium, six one-hundred-thousandth of a milligram of strontium and calcium, and one two-millionths of a milligram of manganese.

Formation of the spectrum

Spectroscopic analysis is based on the distinctively characteristic individuality of the light radiation emitted by the atoms excited from each element present in the sample when it is subjected to a flame

sufficiently hot to dissociate any radicle with which the metal may be combined and to vaporize the metal and ignite the metallic vapor. Every element can be identified with the spectroscope under some conditions.

Every chemist is familiar with the production of spectra with such metals as sodium, lithium, potassium, barium, calcium, and strontium, which are readily volatilized to an incandescent gas at the comparatively low temperature of the Bunsen flame. But when we come to such metals as iron, cobalt, manganese, mercury, chromium, etc., the powerful influence of an arc (4000°C.) or a condensed high tension spark discharge is required to excite their spectra.

There are four general ways of producing luminous excitation or radiation from solid, liquid, or gaseous substances for spectroscopic work; by the simple flame, the arc, the spark and the vacuum tube discharge. In the flame, as already pointed out, only certain elements will emit radiations capable of analytical interpretation. The arc, however, is splendidly adaptable to all the metals and in addition the five non-metals, carbon, silicon, boron, phosphorus, and arsenic, reveal their characteristic spectra. In the vacuum spark, many of the non-metals, among them fluorine, chlorine, iodine, bromine, oxygen, sulphur, and selenium, become detectable as well as the metals. With the spark, "air-lines"—lines of oxygen and nitrogen—are usually in evidence and may cause some interference at times.

The most generally useful of these is the arc spectrum, which consists of the simple production of the arc between two electrodes. Metallic or graphite electrodes of high purity are used, and a small cup is scooped out of the lower electrode. Into this, specimen powders, precipitates, ordinary residues from solutions, etc., are dropped and the arc struck by allowing the electrodes to touch and then separating them by two or three millimeters.

The analysis proper of these emissions involves the dispersing or splitting up the aggregate light from the luminous vapor into their component individual radiations by means of a prism, which are then evidenced as a series of specifically characteristic and invariable, sharp spectrum-lines and bands or flutings, of definite wavelengths. Where the spectra exhibit lines, it is to be concluded that atoms are present in the vapor, and where it is composed of bands, the inference is that the vapor contains molecules. However, for the major part, the spectra are generally line-spectra. Where bands do occur, they are found to be due to the relative inter-vibrations of the atoms of

the molecule which are made up of the emission from the molecules derived from the interaction of the atoms of the electrode material and the atmospheric gases and the moisture which may be present—resulting in the formation of cyanogen and the carbon oxide spectra, consisting of a series of bands, degraded towards the ultra-violet end, the principal heads of which are at 6623, 6299, 6097, 5610, 5198, 4835, 4511, and 4123 A.U. Bands may also be caused by the poly-atomic molecules of the metal electrodes, when such are used, and sometimes by the formation of compounds of the metallic vapor with air-gases. These bands, which present the appearance of continuous darkening in the photographic plate, are in reality made up of very closely packed and frequently inherent faint spectrum lines, which are liable to mask the true line spectrum.

The position of a line in the spectrum is most generally indicated by the wavelength value of the vibrations which produce it. The unit of wavelength is the Ångstrom Unit, or "angstrom" as it is now being called, and it was intended to equal ten-millionths of a millimeter (10^{-7} mm.), and is accordingly often called the "tenth-meter" (1 A.U. = 10^{-10} meter.).

All detectable elements, except fluorine, are determined from their line spectra. However, fluorine may be detected by the arc method³ by the band produced in the presence of calcium, due to the activation of the calcium fluoride molecule. Substances containing calcium and fluorine show a characteristic spectral band which has its head at 5490 A.U., and is degraded towards the infra-red end of the spectrum. Hence fluorine would fail of detection if calcium were absent. Since calcium is a natural constituent of practically all water supplies, the identification of fluorides becomes inevitable.

The extent of the spectrum and the region to be examined

It is interesting to note that the visible spectrum range, which extends from 7500 A.U. to about 4000 A.U., is but a very minute fraction, less than one hundred-thousandth, of the whole spectrum radiated—which extends in both directions far beyond the limits capable of detection by the normal eye. The boundaries of these continuous spectra are quite extensive. By various means, emission spectra have been observed to go as far as wavelength 3,240,000 A.U.—it has been proven that substances radiate energy to an upper limit of 10 times this amount. In the opposite direction, the emis-

sion spectra of some elements have been observed to wavelength of about 150 A.U.

However, the region utilized for practical spectrographic examination begins at wavelength of about 2100 A.U. and ends at just the beginning of the infra-red region at around 7000 A.U. (The infra-red region is considered to extend from 7160 A.U. to 10,000 A.U. and the ultra-violet, or the invisible region, from 3800 A.U. to about 2000 A.U.). The most accurate work is conducted in the ultra-violet region, since it is particularly rich in sensitive radiations and is of a quality more distinctive and refrangible than those which directly affect the human eye. The spectra of the elements for this region have been carefully studied and mapped, and the relative positions of their lines have been accurately determined. The spectrographic examinations of these extreme regions are required to be made photographically, requiring the use of certain brands of photographic plates made especially for this work by photo-sensitizing with the use of various dyes. However, for regions from 2400 A.U. to 5200 A.U., the ordinary photographic plate will serve perfectly well. (The maximum sensitivity of the usual plates lies at or near 4500, which falls off rapidly on the red-side of this to a small value near 5200; while on the short wavelength, the sensitivity falls off more slowly to about 2400, after which it decreases with considerable rapidity.)

Qualitative spectrographic analysis

The qualitative aspect of spectrum analysis has its inception in the fact that in every spectrum there are groups of lines highly and specifically characteristic of the different elements and that these become familiar and recognizable at a glance by those making frequent examinations.

In carrying out a qualitative analysis, the substance held on the graphite electrodes is burned with eight or ten amperes of direct current, with an exposure of 1 to 120 seconds or more, according to the nature of the sample and the region to be examined. Since, as already stated, a majority of the sensitive lines lie in the ultra-violet region of the spectrum, and since these rays are readily absorbed by ordinary glass (glass has a transparency limit of about 3400 A.U.), all parts of the optical train must be of quartz (quartz has a transparency limit of about 1850 A.U.). The light from the burning source is concentrated and focused onto the slit of the spectrograph by means of a quartz condensing lens. The slit consists of sharp,

non-oxidizable, bi-lateral jaws, and is made sufficiently narrow for each color to appear as a line rather than a continuous band of colors. The opening of this slit is generally reduced to the neighborhood of 0.05 to 0.001 mm., in order to obtain maximum resolutions and purity; it is usually fitted with a V-shaped slide wedge, by means of which, the width of the aperture, and consequently the width of the spectrum can be regulated. Figure 1 shows a large Littrow Type Quartz Spectrograph in use.

Not all of the elements are volatilized from a given sample at the same rate, and in order to obtain the true composition of the sample,



FIG. 1. LARGE LITTROW QUARTZ SPECTROGRAPH

provisions must be made to insure its complete volatilization and to record appropriately the average light emitted during the extended burning period. This is readily accomplished by means of a rotating sector disc, driven by a small electric motor, mounted between the light source and the slit so as to periodically interrupt and vary the brightness of the light beam, permitting the necessary reduction of the exposure without shortening the total volatilization time that might be required. The rays from the slit are then resolved and rendered parallel by the lens system of the spectrograph, so that in passing through the dispersing prism the light waves are cleanly bent through angles dependent upon their individual wavelengths, and a

series of slit images as bright line are obtained. The spectra in the invisible region are observed by exposing a sensitized photographic plate for the proper length of time and the photographic record, called a spectrogram, which forms a permanent record, is then examined for results. The photographic procedure is essentially the same as that used in pictorial photography, and the grade of plate to be used will depend upon what part of the spectrum is to be observed. The length of the spectra obtained depends upon the line separation desired and directly upon the dispersion power of the prism employed and general dimensions of the instrument. Adjustments on the larger instruments make it possible to photograph the whole spectrum from about 7000 A.U. to 2100 A.U. on a horizontal plate of 10 x 4 inches by three sectional exposures. Several exposures can be taken on one

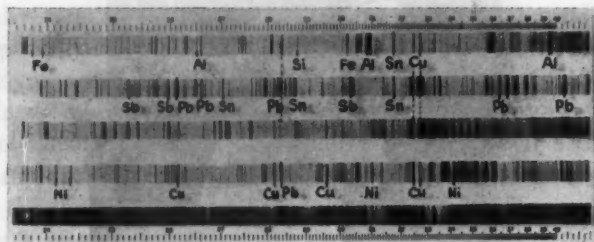


FIG. 2. SPECTRA OF VARIOUS METALS WITH A FEW LINES MARKED FOR IDENTIFICATION

Spectrum 1, aluminum casting alloy; spectrum 2, Babbitt metal; spectrum 3, electrolytic copper; spectrum 4, monel metal; and spectrum 5, iron.

plate, by either raising or lowering the dark slide after each exposure has been completed by racking the slide to a fresh position.

The wavelength determinations are most accurately carried out by the method of comparison spectra. The slit of the spectrograph is covered with a slide having three apertures. The spectrograph is adjusted and the light from a sample is passed through the upper aperture of the slit. Without jarring the spectrograph, the slide is so moved that the lower aperture only is now over the slit. The light from another sample is passed through the instrument. The slide is then moved a third time so that the center aperture alone is over the slit. The light from a pure iron arc is then passed through this aperture. This iron spectrum is used as a standard wavelength scale, to guide in recognizing and indicating the location of a line or

a group of lines of the elements to be identified; it has many lines (running at least to three or four thousand for the region 7160 to 2150 A.U. in the more complete tables⁶), which are well distributed throughout the spectrum and their wavelengths are known to an extremely high degree of accuracy and precision. No science, perhaps, has more important numerical data than spectroscopy. The exact statistics are not known to the authors—a hundred thousand is a conservative estimate. Moreover, wavelengths are measurable with unusually great precision, in many cases better than 1 part per million.

When the plate is developed, a given line due to the iron in each of the two samples will coincide exactly with the corresponding line in the iron arc if there has been no vibration during the exposure. It then becomes a simple matter to “decipher the hieroglyphics of the atoms”—the important lines of the unknown elements are located by simply measuring their position relatively to the neighboring groups of the iron lines in the same spectrum or the adjacent iron spectrum, and determine their exact wavelengths by interpolation. Reference can then be made to an atlas⁷ or a table of wavelengths⁶ and the line becomes accurately identified. Figure 3 shows a reduced copy of single plate from Bardet's Atlas.

Complete measurement of all lines is rarely needed in ordinary chemical analysis, since it is usually necessary to look only for the one or two strongest and most persistent lines of each element to establish definitely its presence or absence. However, in case of doubt, the additional lines will allow for confirmation. The identification is just as certain regardless of whether the element is a common one, or is one of the little known rare elements. For the more exact identification of spectral lines, it is sometimes necessary to measure wavelengths to one or two-hundredths of an angstrom unit. This distance between the lines can be measured with a comparator, a precise instrument that determines the position of all sensitive lines in the spectrogram to those of any known element merely by making the required micrometer-settings.

In cases where it is desired to analyze a complex material containing a large number of ingredients, the above method would be inconvenient because of the large number of spectrum-lines that would have to be identified. It is not essential to have a complete spectrogram of an element in order to identify it in a sample. All that is necessary is that the comparison should show the most important

consists of small quantities of some fifty elements incorporated into an alloyed base material composed of zinc, magnesium and calcium oxides. The quantities of each element present have been most carefully adjusted so that only the most important sensitive lines appear when the powder is volatilized and excited in the arc. All the elements present are evenly distributed throughout the bulk of the powder, so that, under controlled conditions of excitation, the same composite spectrum is always obtained with an average of about seven lines per element. When used as a reference spectrum,

the sensitive lines of all the elements present as "impurities" in the substance under examination, will coincide with the corresponding lines of the standard powder.

This method of qualitative analysis is, of course, very rapid, one half-hour, or less, if the need is urgent, will suffice for the whole procedure of photography, development, and estimation. In addition to this, the plate forms a documentary and irrefutable evidence of the contents of the samples, from which reproductions can easily be made and referred to for supplementary facts as often as needed, even though the sample may no longer be available.

Quantitative spectrographic analysis

Although the use of the spectrograph has been confined largely to qualitative analysis, its scope of usefulness has been extended in the past few years to quantitative work, which is now rapidly assuming great importance.

Quantitative spectrographic analysis is made possible by the fact that up to a given percentage, which is different for each element, the intensities of the characteristic lines of an element are proportional to the relative amount of it present in the substance; and that these lines will progressively disappear, becoming fainter and fainter, as the amount of the element in the light source is reduced. The initially faint lines will vanish first and finally the initially strong lines will follow suit. The latter are referred to as "ultimate lines" or "sensitive lines"—someone has referred to them as the "footprints of the atoms," in that they reveal the minutest traces of an element.

For semi-quantitative estimations, this analysis is generally conducted by a method known as "internal standards." This is carried out by using as a basis of measurement the intensity of the lines due to a major constituent of known concentration and noting the relative difference or intensity ratios between a certain line of the element to be determined and a neighboring line of the main constituent. In the case of water analysis, the intensity lines due to copper, for example, would be compared with the intensity of the lines of the major constituent, calcium. No definite conclusions can be reached by a comparison of copper lines in one sample with the copper lines in another sample, unless the exposures and other conditions of the tests of the two samples are identical. Since this involves considerable technique and manipulation, the internal comparison of copper

and calcium lines in the same spectrum and sample is found to be the more expedient. Some lines are more sensitive to variations than others, and, therefore, some experience is necessary in quantitative estimations of this sort. Again, it is not always possible to find pairs of suitable intensities close enough together on the plate to be used conveniently.

Nitchie⁸ finds it better to add an element having a more convenient spectrum than that of the main constituent. By adding the element in constant known amount, spectrum lines of constant intensity are furnished, from which the percentage of the unknown constituents are estimated. For the more exact quantitative work, he first prepares an accurate set of synthetic standards of the element to be evaluated. The series is then used to obtain standard spectrograms under constant selected conditions. An accurate comparison of the relative intensities of the lines in the different spectra may then be made by measuring photometrically the actual density of the line-images on the original photographic plate by means of a recording densitometer or microphotometer. A calibration curve is thus established by means of which the intensity ratio of the element to be determined can be converted directly to concentration or percent composition.

Methods have also been attempted on the observation of the amount of dilution to which an unknown solution could be submitted before the disappearance of the selected "ultimate lines" took place as compared with that required for a known standard solution.

The precision of this type of testing is being improved progressively by the more recent researches. The U. S. Bureau of Standards is developing a method of photoelectric spectrophotometry which, in time, will afford a most accurate and suitable means for routine testing. Another method which is expected to offer additional reliability and a marked saving in time is also in the state of development and is ingeniously based on the scheme of varying the exposure along the slit of the spectrograph, so as to make the length of the lines some function of their density. For this purpose wedge-shaped images of varying lengths are produced with the use of a rotating sector whose profile is a logarithmic curve or a cam. By introducing this rotating cam in front of the slit, a variation of exposure of time is caused along the length of the slit, and the height of the lines on the spectrogram is then a measure of their respective intensities, see figure 4. By comparing the neighboring minor and main constituent

lines under a travelling microscope and interpolating the respective heights of their peaks, a very accurate quantitative estimation may be had.

It is interesting to note that spectrographic methods of this sort become more precise as the proportion of the test element decreases, while the usual wet analytical methods become less so. Quantitative spectrographic estimations of elements present between 0.001 and 0.05 percent are frequently nearer the correct value than those of the elaborate chemical determinations carried out with no regard to expenditure of time. It may also be stated that a very minute quantity of the sample will suffice for quantitative estimations. So

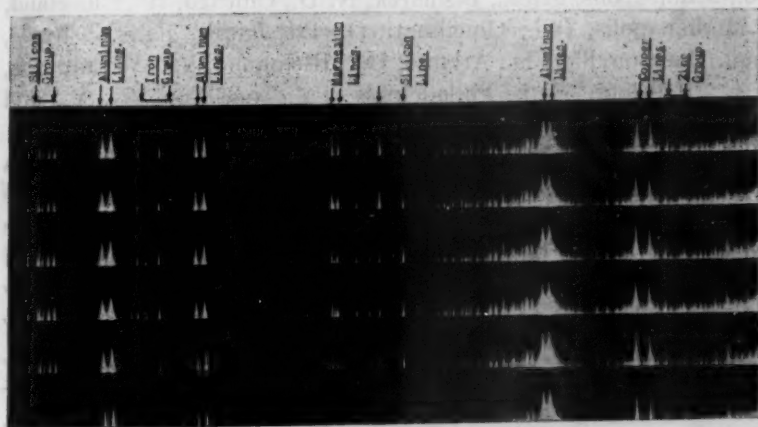


FIG. 4. SPECTROGRAM FROM SECTOR DETERMINATION

long as the portion applied to the electrodes contains 0.01 milligram of the element a determination can be made—0.001 and even 0.0001 milligram have been evaluated in some of the more exacting work. In general, one can easily distinguish between 0.001, 0.01, 0.1 and 1.0 percent of any metallic impurity, while in favorable cases a very much higher accuracy has been obtained.

A more extended account of this type of testing is beyond the scope of this portion of the paper. Further detailed subject-matter on equipment and methods of spectrum analysis is available in a fairly extensive series of publications⁹ for the interested individual who seeks further information.

THE APPLICATION OF SPECTROGRAPHIC ANALYSIS TO SEVERAL UNITED STATES WATER SUPPLIES

This portion of the paper deals with the results that have been obtained and accumulated in a spectrographic survey of the water supplies of a selected number of municipal water-purification plants located throughout the Country, as being typical of some of the various impounded mountain water supplies, surface waters, lake supplies, and artesian wells. Monthly composites of daily samples for February and March from the following 24 cities were examined:

San Francisco, Cal., Helena, Mont., Salt Lake City, Utah, Denver, Col., Sante Fe, N. Mex., Houston, Texas, New Orleans, La., St. Louis, Mo., Minneapolis, Minn., Bismarck, N. D., Chicago, Ill., Cleveland, O., Indianapolis, Ind., Cincinnati, O., Pittsburgh, Pa., Nashville, Tenn., Jacksonville, Fla., Atlanta, Ga., Richmond, Va., Washington, D. C., Baltimore, Md., Philadelphia, Pa., New York, N. Y., and Boston, Mass.

The total solids obtained by evaporation of 2-liter samples on a steam bath and subsequent drying in an oven, were used for the analysis. To prevent "external contamination," considerable care and caution had to be exercised in the scraping and transferring of these residues to specimen vials. The spectrograms were readily prepared by burning a few milligrams of the residue in a small cavity of a spectroscopically pure carbon electrode, as already described. These spectrograms have been taken in two positions, the first covering the region from about 7000 A.U. to 3250 A.U., and the second, from 3250 A.U. to about 2400 A.U.

In this work, spectrographic identification and the semi-quantitative estimations were limited to the lesser known or minor chemical elements of natural waters, with no particular attention given to chemical elements capable of ordinary quantitative determination, such as, calcium, magnesium, iron, and silicon, for example. To check the accuracy of the spectrographic estimations, the concentrations of aluminum, sodium and potassium were determined and were found to be in close agreement with the data obtained by chemical methods.

Results obtained

Some 30 elements were spectrographically determined on the 24 samples, and it is believed that no other elements are present except those reported. In fact, so that no element might be missed, every

line in the spectrum of the Cleveland sample was identified. This virtually takes care of all elements except the halogens and those elements forming part of the anions.

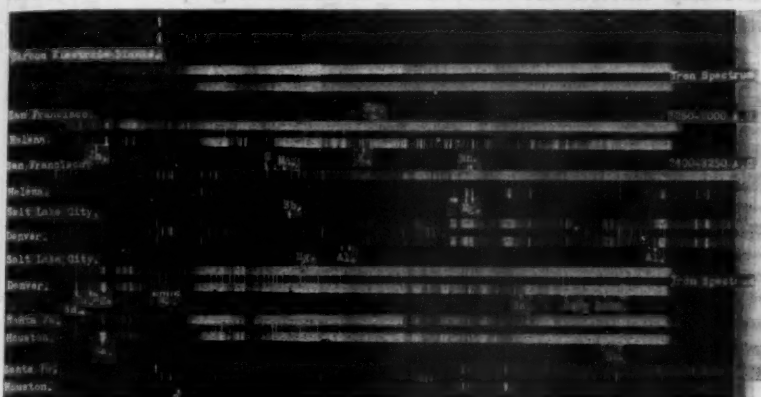


FIG. 5. SPECTROGRAMS FOR THE REGIONS 7000 TO 3250 A.U., AND 3250 TO 2400 A.U., FOR BLANKS ON CARBON ELECTRODES AND FOR SAMPLES FROM SAN FRANCISCO, HELENA, SALT LAKE CITY, DENVER, SANTA FE, AND HOUSTON

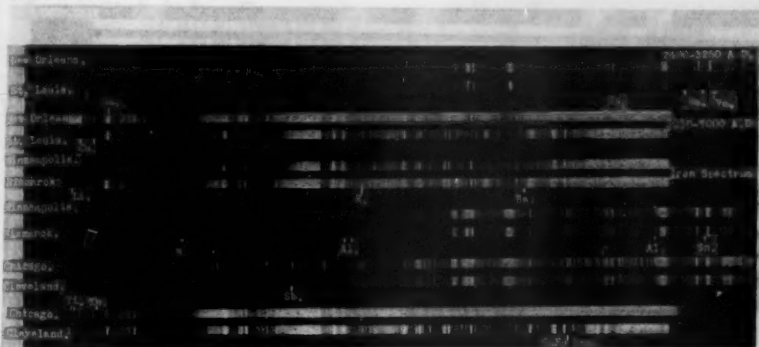


FIG. 6. SPECTROGRAMS FOR THE REGIONS 7000 TO 3250 A.U., AND 3250 TO 2400 A.U., FOR SAMPLE FROM NEW ORLEANS, ST. LOUIS, MINNEAPOLIS, BISMARCK, CHICAGO, AND CLEVELAND

Spectroscopically pure carbons have been recently put on the market by the National Carbon Company. Some of them are 99.9999 percent carbon. The set used for these analyses contain, only in the faintest traces, calcium, magnesium, silicon, aluminum,

and copper—blank spectrograms for these are shown on figure 5. These elements caused no difficulty since they are present in all water samples investigated. The spectroscopic analyses which we have previously carried out² were done on Acheson graphite electrodes. Titanium and vanadium were found, at that time, in practically all

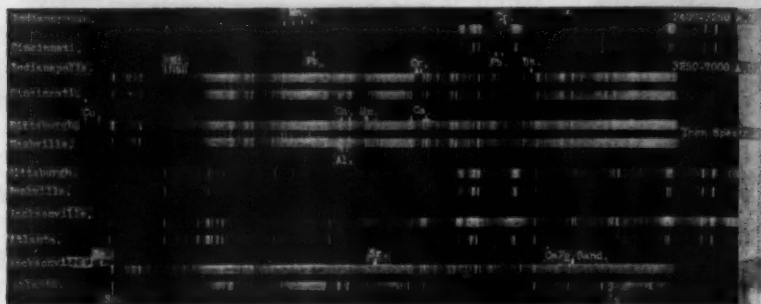


FIG. 7. SPECTROGRAMS FOR THE REGIONS 7000 TO 3250 A.U., AND 3250 TO 2400 A.U., FOR SAMPLES FROM INDIANAPOLIS, CINCINNATI, PITTSBURGH, NASHVILLE, JACKSONVILLE, AND ATLANTA

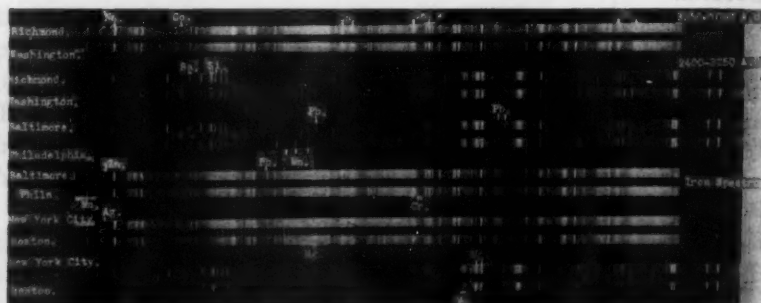


FIG. 8. SPECTROGRAMS FOR THE REGIONS 7000 TO 3250 A.U., AND 3250 TO 2400 A.U., FOR SAMPLES FROM RICHMOND, WASHINGTON, D.C., BALTIMORE, PHILADELPHIA, NEW YORK CITY, AND BOSTON

samples of water residues arced on Acheson graphite. In this work, vanadium was found in but one sample, occurring as a small trace in the St. Louis supply. Titanium was found in about one-half of the samples examined. Electrode contamination was probably responsible for the reports of titanium and vanadium previously made. It

TABLE 1
General data

CITIES	SOURCE OF WATER SUPPLY	TOTAL SOLIDS	AVERAGE CHEMICAL ANALYSES (expressed in parts per million)						
			Ca.	Mg.	Na.	K.	SO ₄	Cl.	
San Francisco.....	Impounded mountain water supply	175.0	28.0	12.0			39.9	28.4	
Helena.....	Mountain stream, ten mile system	91.0	8.0	3.0	11.0		29.0	1.0	
Salt Lake City.....	Canyon streams, snow run-off, 3 creeks	225.0	46.4	18.0	6.1	5.7	21.6	18.6	
Denver.....	South Platte River, Bear and Cherry Creeks	202.0	32.0	10.0	23.0	2.4	43.0	31.0	
Santa Fe.....	Mountain stream, 11,000 feet	76.0	15.0	9.0	Trace	Trace	22.0	12.0	
Houston.....	Deep well supplies, average depth 1200 feet	495.0	28.0	5.5	125.0		3.0	54.0	
New Orleans.....	Lower, Mississippi River	100.0	15.0	3.0	13.0		21.0	9.9	
St. Louis.....	Middle, Mississippi River	400.0	49.0	33.1	59.0		103.8	31.0	
Minneapolis.....	Upper, Mississippi River	275.0	43.7	15.4	4.4		35.9	3.6	
Bismarck.....	Upper, Missouri River	458.0	52.1	22.2	32.4		160.4	7.0	
Chicago.....	Lake Michigan	147.0	33.6	10.0	3.6	1.0	12.4	5.5	
Cleveland.....	Lake Erie	164.0	34.7	8.7	3.8		20.6	16.0	
Indianapolis.....	White River Watershed, rainfall 67% low	390.0	82.0	39.0	13.0		69.0	22.0	
Cincinnati.....	Lower, Ohio River	207.0	34.0	6.1			72.9	22.0	
Pittsburgh.....	Allegheny River, Kiskiminetas' Mine wastes	202.1	25.2	6.2	17.8		95.6	16.0	
Nashville.....	Cumberland River	136.8	39.1	4.2	3.6		31.0	4.7	
Jacksonville.....	Artesian Wells, 770 to 1150 feet deep	398.0	68.0	26.0	15.0	4.4	142.0	17.0	
Atlanta.....	Chattahoochee River	42.2	4.2	0.6	2.0		6.1	3.1	
Richmond.....	James River	100.0	16.4	2.6			20.5	5.5	
Washington, D. C.....	Potomac River	140.0	28.3	2.4			29.1	5.4	
Baltimore.....	Gunpowder Rivers	72.8	14.9	3.5	2.0		12.0	5.3	
Philadelphia.....	Schuylkill and Delaware Rivers	161.0	23.3	8.1			51.0	8.1	
New York City.....	Impounded mountain water, Catskill system	52.0	9.4	2.9	2.0	1.0	13.4	3.0	
Boston.....	Impounded mountain water, Chestnut Hill and Weston Reservoirs	38.7	7.0	0.6				3.7	

TABLE 2
Semi-quantitative data on minor chemical elements identified spectrographically in the solid residues of the various composite water samples
(Results are expressed in parts per million)

	Al.	Ba.	B.	Cu.	Cr.	F.	Pb.	Ni.	Mn.	K.	Na.	Ag.	Sr.	Sn.	Zn.
San Francisco.....	0.7	0.2	0.1	0.2	0.01	Tr.	0.002	0.000	0.2	0.02	9.0	0.05	2.0	0.000	0.08
Helena.....	0.4	0.1	0.01	0.3	0.002	0.05	0.001	0.000	0.05	1.0	5.0	0.03	1.0	0.03	0.2
Salt Lake City.....	0.7	0.2	0.1	0.04	0.002	Tr.	0.002	0.02	0.002	0.02	10.0	0.06	2.0	0.02	0.08
Denver.....	1.0	0.2	0.08	0.6	0.002	0.5	0.002	0.04	0.002	1.0	10.0	0.2	2.0	0.02	0.08
Santa Fe.....	0.2	0.07	0.02	0.01	0.001	0.07	0.004	0.000	0.001	0.07	0.7	0.02	0.1	0.02	0.07
Houston.....	1.0	0.4	0.4	0.1	0.01	Tr.	0.005	0.000	0.005	0.2	30.0	0.1	4.0	0.05	0.01
New Orleans.....	0.1	0.1	0.06	0.05	0.002	Tr.	0.001	0.001	0.000	0.2	6.0	0.08	1.0	0.001	0.03
St. Louis.....	0.2	0.2	0.5	0.2	0.01	Tr.	0.005	0.005	0.000	0.9	3.0	0.01	5.0	0.005	0.1
Minneapolis.....	0.2	0.3	0.15	0.05	0.000	Tr.	0.003	0.003	0.05	0.05	4.0	0.01	1.5	0.005	0.005
Bismarck.....	1.0	0.5	1.0	0.1	0.000	Tr.	0.01	0.005	0.000	1.0	25.0	0.01	10.0	0.1	0.005
Chicago.....	0.6	0.07	0.07	0.07	0.002	Tr.	0.002	0.002	0.003	0.02	2.0	0.02	2.0	0.04	0.2
Cleveland.....	0.1	0.3	0.08	0.05	0.002	0.1	0.02	0.002	0.002	0.07	5.0	0.02	5.0	0.02	0.02
Indianapolis.....	0.4	0.4	0.1	0.1	0.04	0.1	0.04	0.3	0.3	0.5	20.0	0.04	4.0	0.000	0.04
Cincinnati.....	0.2	0.15	0.02	0.03	0.002	Tr.	0.15	0.000	0.000	0.1	6.0	0.02	1.5	0.02	0.02
Pittsburgh.....	0.4	0.2	0.06	0.1	0.002	Tr.	0.02	0.005	0.3	0.2	10.0	0.02	2.0	0.02	0.02
Nashville.....	0.4	0.1	0.01	0.01	0.001	Tr.	0.01	0.001	0.1	0.02	2.0	0.01	1.0	0.001	0.01
Jacksonville.....	0.4	0.3	0.12	0.05	0.004	0.2	0.04	0.004	0.004	0.1	10.0	0.04	10.0	0.004	0.2
Atlanta.....	0.2	0.04	0.04	0.02	0.004	Tr.	0.004	0.001	0.005	0.03	2.0	0.04	0.2	0.01	0.1

Richmond.....	0.3	0.05	0.1	0.01	0.002	Tr.	0.01	0.01	0.05	0.1	4.0	0.02	1.0	0.002	0.03
Washington.....	0.4	0.15	0.02	0.02	0.002	Tr.	0.02	0.000	0.15	0.15	5.0	0.02	1.5	0.002	0.03
Baltimore.....	0.2	0.03	0.04	0.005	0.005	0.02	0.18	0.002	0.005	0.04	1.5	0.01	0.4	0.005	0.06
Philadelphia.....	0.3	0.1	0.02	0.02	0.01	0.01	0.02	0.01	0.3	0.06	6.0	0.03	1.5	0.01	0.03
New York City.....	0.2	0.05	0.01	0.01	0.007	0.01	0.04	0.000	0.07	0.04	2.0	0.05	0.5	0.005	0.01
Boston.....	0.1	0.05	0.03	0.02	0.005	0.01	0.02	0.000	0.04	0.03	1.5	0.05	0.5	0.005	0.01

Remarks: 0.2 p.p.m. lithium in Bismarck; traces in St. Louis, Denver, Helena, Philadelphia, and Pittsburgh; 0.04 p.p.m. antimony in Salt Lake City; traces in Cleveland, Philadelphia, Baltimore and Pittsburgh; 0.02 p.p.m. vanadium in St. Louis; nil in other samples; 0.07 p.p.m. titanium in Chicago; 0.02 p.p.m. in San Francisco, Denver, Washington, New York City, traces in Salt Lake City, Houston, Atlanta, Richmond, Baltimore, and Boston; traces of molybdenum in Atlanta, Pittsburgh, Indianapolis, Bismarck, St. Louis, Houston, and Denver; and traces of cobalt in Philadelphia, Richmond, and Pittsburgh.

is believed that this paper records a qualitative and a semi-quantitative analysis in which there is no contamination from blanks or reagents. Elements which are reported must be in the sample of dry solids submitted.

The spectrograms obtained have been arranged into figures 5, 6, 7 and 8 conveniently notated and appropriately supplemented by tabulated data (tables 1 and 2). These data are of a semi-quantitative nature and were obtained from the spectrograms by interpolation with the method of "internal standards."

Discussion of results

The following elements were found in chemically determinable amounts in all samples; calcium, sodium, magnesium, silicon, aluminum, iron, copper, and boron. Strontium was found to be present in appreciable amounts in all samples. In the chemical analysis of calcium, therefore, an appreciable error will be introduced if the amount of strontium in the calcium oxalate precipitate is counted as calcium. As high as 10 p.p.m. of strontium are probably present in some cases.

Barium is also present in every sample, but in much smaller amounts. Barium in water is an example of an element which could be very advantageously determined quantitatively by the spectrographic method. Its chemical estimation would be difficult, while its spectrographic determination would be simple and rapid once standards were determined. Other elements present, at least in traces, in all samples, are: potassium, copper, silver, and zinc. Titanium, tin, lead, chromium, manganese, fluorine, and nickel are present in most samples.

Silver was identified in traces in all supplies and was found to occur in appreciable amounts in the waters supplied to New York City, Atlanta, New Orleans, and Denver. The water supply of Denver may contain as much as 0.2 to 0.3 p.p.m. of soluble silver. The water supplies of Atlanta and New York City apparently contain more silver than copper. The highest zinc content was found to occur in Lake Michigan water, ranging between 0.2 to 0.3 p.p.m. Chromium was identified in faint traces in all cases. Nickel occurred as a spectroscopic trace in all supplies excepting those of Denver and Indianapolis. The Denver supply may contain as much as 0.5 p.p.m., being higher than the iron. In the Indianapolis supply the amount reaches about 0.3 p.p.m.

The waters of the east in general contain about the same amount of boron as the waters of the west. The parts per million may be less in some cases, but the percents of boron on the total solids are very similar. The supply of Bismarck contains the highest boron, about 1 p.p.m. Fluorine can, however, be detected in many of the eastern samples, such as those of Boston, Baltimore, and Jacksonville. Lead seems to be higher in the eastern samples, occurring in the western samples in spectroscopic traces only. The only samples to contain appreciable amounts of lead were those of Baltimore and Cincinnati, containing respectively 0.18 and 0.15 p.p.m. Pb. The manganese average of the western supplies is considerably lower than the average for the east. Some sand filters quantitatively remove manganese so that not even a spectroscopic trace remains in the effluent. The waters of Indianapolis, Pittsburgh, Nashville, Washington, and Philadelphia, however, contain appreciable amounts of manganese. In some cases aluminum is lower in the alum coagulated and filtered water supply than in an untreated one, e.g., there is less aluminum in a sample from Cleveland than in the sample from Chicago. Further interesting comparisons may be obtained by referring to the tabulated data. In connection with this, it should be mentioned that in the case of those cities having more than one source of water supply, the samples submitted were composited into a single sample.

In concluding this discussion, the authors wish to emphasize the following points. The results reported should not be misconstrued to mean that all of these metallics occur in such regular concentrations at all times, as it is quite probable that the content of these "trace elements" will fluctuate more widely than might be appreciated—depending to a large extent upon the geological and stream conditions along the watershed—so that a single sample which might show minimum quantities of a given element, or even its complete absence, might at another time indicate a momentary and an appreciable increase in concentration. Results of Baltimore and Cincinnati might serve as particular examples of such a variation. On the March sample for this survey, the lead content for Baltimore was reported as 0.18 p.p.m. Pb., which was later checked as 0.08 p.p.m. Pb. on another sample collected in July. Whereas, 0.15 p.p.m. Pb. was reported for Cincinnati in this same survey and 0.02 p.p.m. Pb. in the Ohio survey of 1933.² We can, therefore, assume that similar variations might be expected in the other constituents present in the supplies.

On the other hand, spectroscopy is not entirely without pitfalls. While the spectrograph never tells a lie, the observer may not always read and interpret the truth. It is conceivable, with the extreme delicacy of this type of testing, that the "external impurities" which might be introduced from piping, pump, and faucet metals, etc., would probably contribute their quota to the spectra recorded. Just what might be encountered in this direction is difficult to say; nevertheless, it would most probably be limited to only a few of the more common metals. In this connection, the authors were mindful of the fact that there were a number of factors beyond their control which might vitiate the results. To reduce these to a safe minimum, the collaborators were instructed to exercise the utmost care in the collection of the water samples and the subsequent preparation of the residue specimens. Evaporations were conducted in glazed-porcelain evaporating dishes, and the residues were transferred with particular care so as to not contaminate them with broken bits of the metal spatula or other scraping implements. On the whole, it is felt that these precautionary measures met with their due amount of respect, and that the results reported herein are therefore a fair approximation of the truth.

In closing, the authors feel that a mere beginning has been made and that further refinement will, in time, permit more critical and exacting tests. It is sincerely hoped that this paper has, in a small and preliminary way, added something to existing knowledge of the water works fraternity, and that it will at least serve to indicate another avenue of approach in the field of water analysis, especially where interests might go beyond the limitations of ordinary laboratory analyses.

ACKNOWLEDGMENT

The authors wish to take this opportunity to acknowledge gratefully their indebtedness to the operators of the various water-purification plants for their coöperation in the collection and the preparation of samples for this survey. In like manner, we wish to extend our thanks to Mr. Charles C. Nitchie of the Bausch and Lomb Optical Company, and to Mr. Sheppard T. Powell, Consulting Chemical Engineer, Baltimore, Md., for their kind interest and many favors; and also to Mr. Harry E. Jordan, Chemical Engineer, Indianapolis

Water Company, whose interest and suggestions have stimulated the incentive for this particular survey.

(Revised form of paper presented before The Water Purification Division, the New York Convention, June 5, 1934.)

REFERENCES

- (1) Departmental Report on the Experimental Work on the Utilization of "Aluminum Dross-Fines" as a Source of Aluminum Sulphate for the Coagulation of the Cleveland Raw Lake Water. Baldwin Filtration Plant, Department of Public Utilities, City of Cleveland, August 25, 1933.
- (2) Spectrographic Analysis of Water with Special Reference to Several Ohio Supplies. Mathew M. Braidech, Senior Chemist, Baldwin Filtration Plant, Cleveland, Ohio, and F. H. Emery, Spectrographer, National Smelting Co., Cleveland, Ohio. Presented to the 13th Annual Ohio Conference on Water Purification with the State Dept. of Health, October, 1933, Findlay, Ohio.
- (3) Spectroscopic Detection of Fluorine. J. Papish, L. E. Hoag, and W. E. Snee. Industrial and Engineering Chemistry, July 15, 1930.
- (4) The Occurrence of Fluorides in Some Waters of the United States. H. V. Churchill. Jour. Amer. W. W. Assoc., September, 1931.
- (5) Spectrographic Analysis. Professor Roscoe, Cornell University, Sibley Jour. of Eng., June, 1932.
- (6) Wave Length of the Principal Lines in the Emission Spectra of the Elements. Handbook of Chemistry. N. A. Lange. Handbook Publishers, Inc., Sandusky, O. 1934. (Book)
- Wave Length Tables for Spectrum Analysis. F. Twyman and D. M. Smith. (Book) Second Edition. Adam Hilger, Ltd., London, 1931.
- International Critical Tables. (Book) Vol. V. McGraw-Hill Book Co., New York.
- (7) Atlas De Spectres D'Arc. Jacques Bardet. (Book) Paris—Gaston Doin and Cie, 1926.
- Tabelle Der Hauptlinien Der Linienspektra Aller Elemente. H. Kayser. (Book) Julius Springer, Berlin, 1926.
- (8) An Improved Method of Quantitative Spectrographic Analysis. C. C. Nitche and G. W. Standen. Industrial and Engineering Chemistry, Anal. Edition, 4, 1932.
- (9) The History of the Development of the Art of Spectrographic Analysis. U. S. Bureau of Standards Scientific Paper No. 444 (1922). Washington, D. C.
- Foundations and Methods of Chemical Analysis of the Emission Spectrum. (Book) Walter Gerlach and Eugene Schweitzer, Physical Institute of Munich. Translated by Adam Hilger, Ltd., London, 1929.
- Quantitative Spectrum Analysis. F. Twyman and D. M. Smith. Technical Publication No. 79—American Inst. of Mining and Metallurgical Engineers, 1928.

- Quantitative Analysis with the Spectrograph. C. C. Nitchie. Industrial and Engineering Chemistry, Anal. Edition, 1, 1929.
- Spectrum Analysis in an Industrial Laboratory. W. H. Bassett and C. H. Davis. Trans. Amer. Inst. Mining and Metallurgical Engineers, 68, 662, 1922.
- Quantitative Spectrographic Analysis of Solutions. W. Brode and J. Steed. Industrial and Engineering Chemistry, Anal. Ed. 6, May, 1934.
- Some Useful Applications of a Quartz Spectrograph. F. A. Hull and G. Steele. Proc. Amer. Society for Testing Materials, 27, 284, 1927.
- Instruments and Methods used for Measuring Spectral Light Intensities by Photography. G. R. Harrison. Jour. Optical Soc. Amer. & Rev. Sci. Inst., 19, 267, 1929.
- Photographic Spectrophotometry in the Ultra-Violet. L. A. Jones. Bulletin National Research Council, No. 61, 1927.
- Photographic Plates for Use in Spectroscopy. C. E. K. Mees. Jour. Optical Soc. Am., 21, 753, 1931.
- The Spectroscope and its Uses in General Analytical Chemistry. T. T. Baker. (Book) William Wood and Co., New York, 1923.
- Spectroscopy in Science and Industry. S. J. Lewis. (Book) Scientific American Publishing Co., New York, 1933.
- Cantor Lectures by Dr. F. J. Lewis. (3 Lectures.) Jour. of the Royal Society of Arts, October 14, 21, and 28, 1921. London.
- Spectroscopy in the Past and in the Future. Chas. Fabry. Jour. of the Franklin Institute, September, 1924. Philadelphia.
- Spectroscopy. E. C. C. Baly. (Book—4 vols.) Longmans, Green and Co., London, 1924-1929.
- Introduction to Atomic Spectra. H. E. White. (Book) McGraw-Hill Book Co., Inc., New York, 1934.

SEARCH FOR UNDERGROUND WATER IN PERPETUALLY FROZEN AREAS

By M. J. CHERNYSHOFF

(Mechanical Engineer, Professor of Polytechnic Institute,
Wladivostok, U. S. S. R.)

In the North regions of Europe, Asia and North America one can find vast areas, containing grounds and layers with temperatures below water freezing point not only during winter, but all the year around, on a certain depth from the surface exposed to sunlight to 300 feet lower down.

Frozen states of grounds persisting for several years are called perpetually frozen.

In the opinion of the hydrologists grounds perpetually frozen are of great interest, because a complicated process of water formation is always going on in the ground crust as well as the water's fight against perpetual freezing.

The North regions of the continents are rarely populated, but contain considerable natural resources: woods, ore minerals, noble metals, furs etc. By making the most of these natural resources industrial enterprises and roads always very frequently require considerable water supply.

Because of insufficient knowledge of this question, finding water in grounds perpetually frozen offers great difficulties and the methods used to find it cannot be those ordinarily used.

This article gives an account of the methods of water search in perpetually frozen grounds, developed in the author's twenty year's practice in the Far East, U. S. S. R.

These methods are closely associated with common geological practice and with the climate of the previously mentioned region. It is possible that they cannot be transferred completely to other conditions, but in many cases they can still be put to use in other lands, particularly in Alaska.

The following facts are at present available: (1) the presence of water in thick alluvium above perpetually frozen grounds; (2) the presence of water, found on the surface of the earth in the form of

hidden and open springs, rising from very deep strata and burrowing their way through the veins of the thick ground mass in regions with perpetually frozen grounds and (3) the possibility of water-supply in some locations by means of bores from under thick ground masses in regions with perpetually frozen grounds.

We shall call the first subsoil-water, the second spring-water and the third artesian-water.

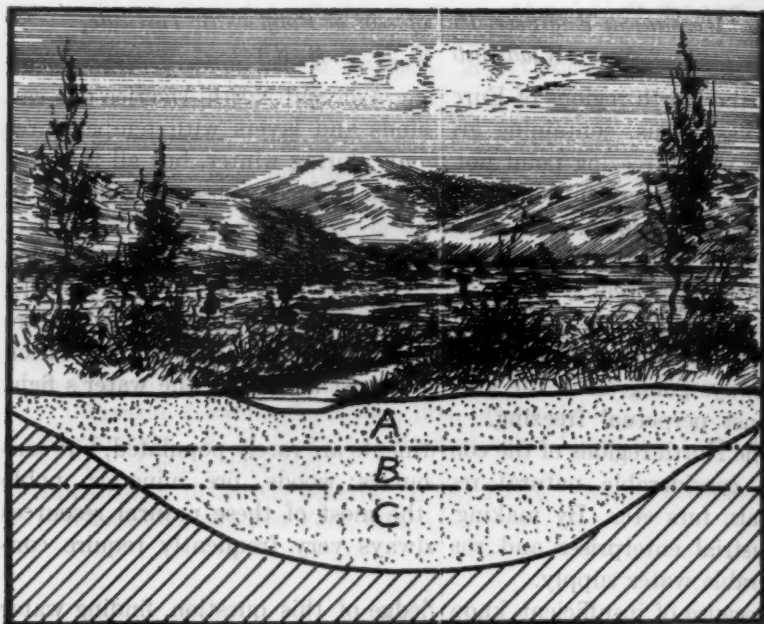


FIG. 1. DESIGN OF THE SECTION ALONG THE VALLEY CROSSED BY SUBSOIL WATER

A, Frozen ground's layer; B, Thawed layer, containing water; and C, Perpetual freezing.

SUBSOIL WATERS

Subsoil waters in regions with perpetually frozen grounds are formed by the infiltration of atmospheric precipitation as well as by condensation of moisture chiefly in frostless seasons.

The settlement of the subsoil-water takes place in the thick alluvial soil of the fluvial valleys. These alluvial soils in consequence of their perpetually frozen bedding and deep winter freezing of their

upper layer cannot appear as powerful accumulators of water. Therefore, subsoil-water of the upper frozen layers is characterized by extremely inconstant delivery and often dries up towards the end of winter.

In winter when the ground is frozen, the water-bearing layer in the thawed wedge appears to be compressed between the winter frozen ground and the layer of the perpetually frozen ground (fig. 1). At further freezing of the ground and of some point of the whole water-



FIG. 2. ICE-FIELD FORMED BY THE UNDERGROUND WATER'S OUTLET ON THE SURFACE IN THE BORDERS AND THE RIVER'S VALLEY ITSELF

bearing layer in the lower part of the slope, a considerable hydrostatic compression occurs in the stream and, due to it, a break and water course on the surface results in the most unsteady points of the upper frozen layer (fig. 2).

The water which burrows its way through the surface freezes and forms an "ice-field." These ice-fields must be differentiated from those which are formed by spring-water. On the grounds, where heated buildings are located, water can come out across this ground with less resistance and can fill abundantly not only the ground under

buildings, but the lodging itself (fig. 3). As grounds thaw gradually, these faults disappear and the water often dries completely up.

The ice-fields formed by subsoil-water are not permanent in their place and often shift depending on the heat change of separate platforms of the surface. Figure 4 serves as an example of the formation of ice-fields along the newly located unpaved highway, under whose road-bed freezing of the water-bearing layer and in consequence a frozen barrier took place.



FIG. 3. ICE-FIELD FORMED IN THE HEATED UNDERGROUND OF THE BARRACKS

It is seen by its character that subsoil-water bedded in the upper frozen layers generally cannot serve as an abundant and dependable spring and therefore it offers only insignificant water-supply.

The best thing to do with the concentration of subsoil-water is to erect common shallow wells with timbered frames or underground drain galleries. During the arrangement of the gallery it is necessary to consider that intensive development of water exhausts to a great extent the water-bearing layer and reduces the depression, which provokes in turn an increased freezing of the ground from the surface and may lead to total freezing of the galleries.

In order to prevent the freezing of water-supply, the wells must be provided with tight covers. The mouth of the well must have an earth cover over a large radius.

It is also necessary to preserve a water-holding underground gallery from freezing by means of an earth embankment of some height, erected on the level of the gallery.

It is advisable to determine the use by the assembled buildings during the most unfavorable season, i.e., March, by means of pump tests, as the water-supply is not reliable in the perpetually frozen grounds.



FIG. 4. ICE-FIELD FORMED ALONG THE ROADWAY IN CONSEQUENCE OF FREEZING OF THE WATER-BEARING LAYER

The underground water in the regions with perpetually frozen grounds is characterized by softness and sometimes by high amounts of iron.

SPRINGS

Springs are more constant and more abundant. Springs generally appear in the cracks of the scraps in the districts of deserted sections. These springs according to Prof. W. A. Lwow's theory are of young origin.

Granite and all sorts of crystalloid schists are particularly fruitful

in rising flow streams. Flow streams come across as mineral and fresh waters. Some waters are aerated by carbonic acid or nitrous acid. Carbonic acid waters are for the most part cold, but nitrous acid waters warm and hot.

For the most part springs come out on the surface exposed to sunlight over the slopes of the valleys and also on the tops of the mountains themselves. After having forced their way through the per-

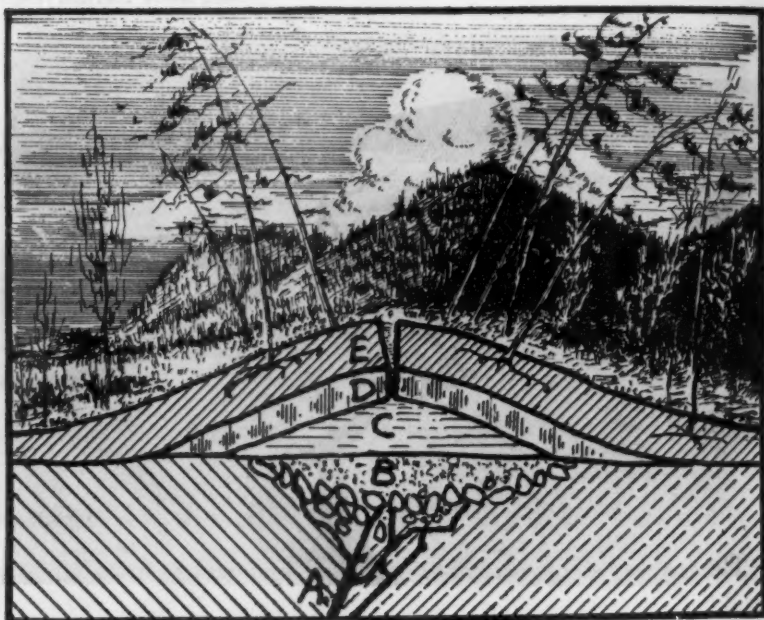


FIG. 5. CROSS-SECTION OF THE SPRING OUTLET'S IN WINTER-TIME

A, Fissure on the contact of two layers; B, Tunnel with broken pieces of rock and mellow sediments; C, Water-accumulation in winter-time; D, Ice under ground; and E, Ground with vegetation.

petually frozen grounds they pour out through broken pieces of rocks under cover of vegetation, and in summer-time they saturate abundantly the alluvial soil on the perpetually frozen grounds. In such cases, thanks to the warmth of the water the springs' course and their upper part are distinctly marked by dense thickets of trees with hillocks, including ice lenses with inclined trees on different sides (fig. 5).

On the tops of such a thicket and near the passage out of the spring

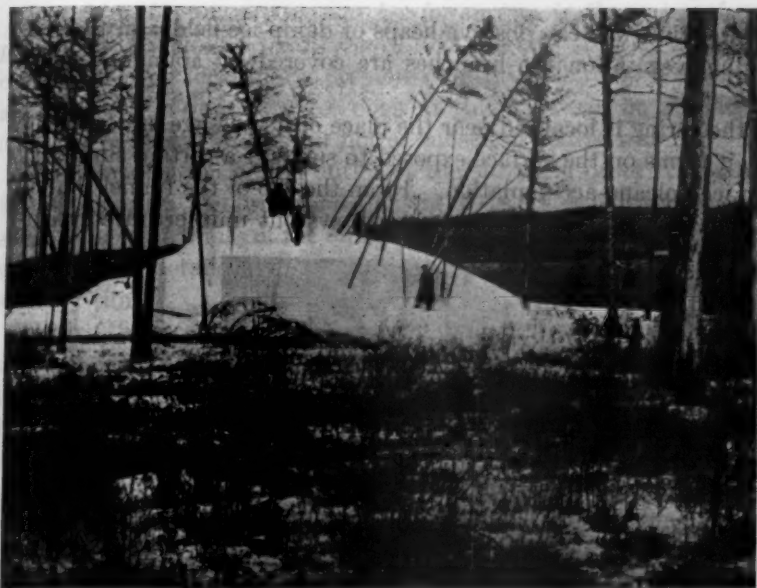


FIG. 6. ICE-HILLOCK FORMED AT THE OUTLET OF THE SPRING AND DISCHARGING WATER



FIG. 7. WATER CRATER ON THE TOP OF AN ICE-HILLOCK

in winter-time one can observe heaps or damp ice-fields; on the surrounding vegetation the branches are covered by abundant white frost.

If the spring is localized near the place of its passage out from the rock, it forms on the surface exposed to sunlight a certain similarity to an ice volcano-accumulation. From the top of the funnel-shaped openings of such volcanos the water flows out uninterruptedly, in-



FIG. 8. OPEN HEAD OF THE SPRING AT THE BORDER OF THE ICE-FIELD UNDER THIN ICE IN MARCH

creasing the height of the cone during freezing and forming below the ice-field an ice heap (fig. 6) similar to lava (fig. 7).

There are often cases when the spring, flowing out on the surface exposed to sunlight, forms a visible stream and during winter-time, due to a relatively high temperature, its water has time to flow out from the place of its outlet under a thin ice cover. Below the slope the water freezes and forms considerable ice-fields—flat and hilly.

Figure 8 represents the open head of the spring (place of outlet) in the border of a vast ice-field. The location of this head was discovered by hearing the noise of water under the ice-cover.

It is advisable to carry on searches for springs in the region of perpetually frozen grounds in February and March. At this time it is easy to fix their location by previously mentioned symptoms, heaps and ice-fields. Besides water open at this time can be absolutely accepted as spring-water, but not as subsoil or source water.

The investigation of the outlet of the spring in order to concentrate it consists in boring and digging at two steps, (1) reconnaissance, when the limits of the outlet of the spring are fixed, in March, and (2) the detailed exploitation and concentration of water in summer-time.

During the reconnaissance investigation one makes the topographical survey of the place of the spring's outlet and the drawing of the ice-field's limit. The velocity of the water is observed in the running ice-fields. The approximate place of the spring's outlet is determined by the direction of the water's course, and in rare cases one can also establish its exact origin. The water's temperature is taken by its velocity. The rise of temperature points out approximately the outlet's place. One tries to find the thawed earth-layers in the limits of the water's outlet by shallow borings and excavations, and temperature is taken in them. The deepening of the thawed earth layers and the rise of temperature therein are symptoms of the water's outlet.

In the case of a spring's opening by its own discharge, its yield may be fixed with the help of sumps. The sump on the spring's opening is represented on figure 8, foreground.

It is necessary, in consequence of the considerable length of ground and ice-field flow and of the uncertain spring's head, when going up the slope, to find by feeling, by means of shallow borings and diggings, the limit of the thawed earth-layers, which taper off gradually when climbing on the slope, taking into consideration that the top of the parabola's curve must lead to the spring's head.

If the main spring flows out on the top of the ice cone from a funnel in the form of a crater, it is necessary to search in its region, as experience shows that such cones are often formed, generally at the end of winter's time, in the spring's head. At any rate one can often find by feeling thawed earth's layers under them.

The definition of the funnel of the thawed earth's layers, in the depth of which the spring's outlet is to be found, is performed by *detailed investigation of the spring* and by concentration. With this in mind chess board order borings are made on the platform of the spring's outlet at depths as far as the continental layers (fig. 9).

On the basis of the materials of these pitholes one compiles summary geological plans with notations of the borderland of perpetually

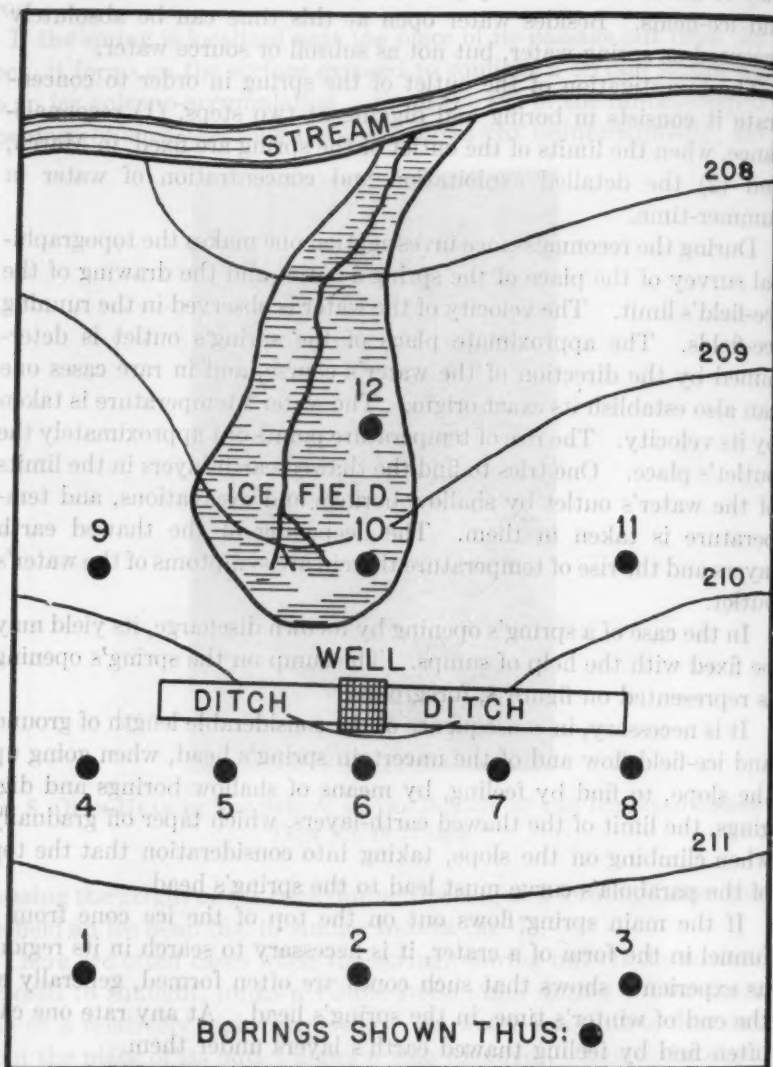


FIG. 9. PLAN FOR SPRING INVESTIGATION

frozen grounds and water level. In the center of the upper horizon's funnel of the perpetually frozen grounds in continuous thawed earth's layers one makes at the depth of radical layers (rocks) an

excavation or boring of suitable dimension for pumping out water (fig. 10).

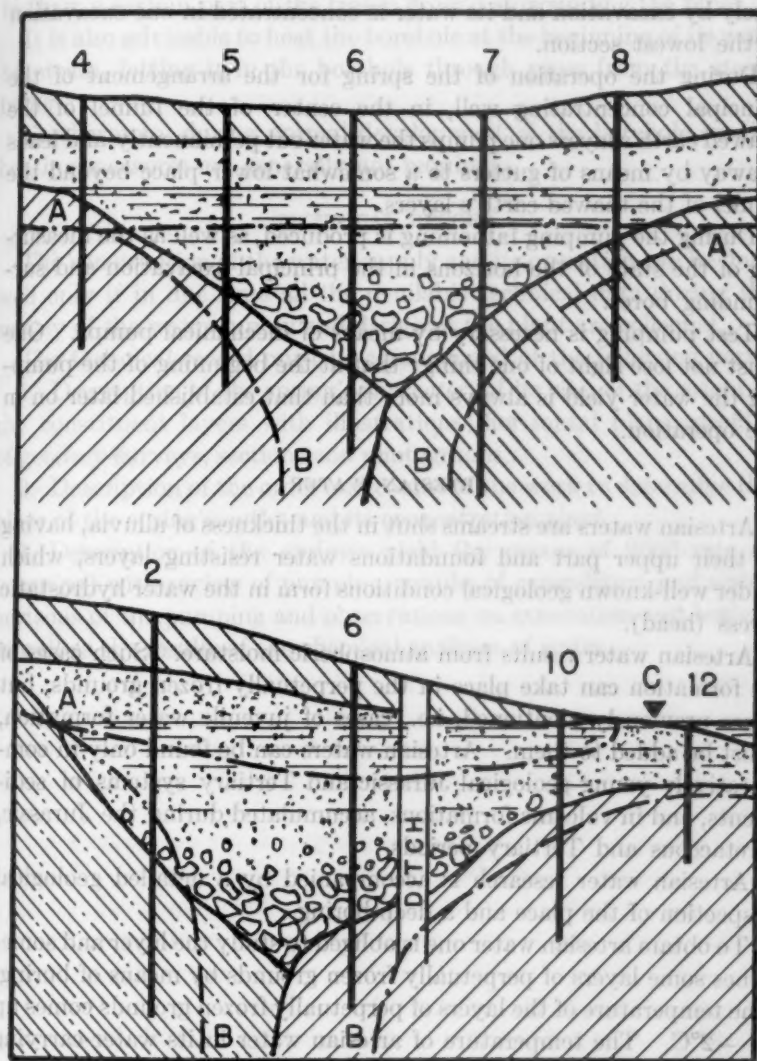


FIG. 10. GEOLOGICAL CROSS-SECTIONS AT SPRING'S OUTLET ON THE SURFACE

When the spring's outlet is discovered the whole thawing earth's layers and water's outlet from them are intersected in several points by a water-collection gallery.

In consequence of the dispersion of the springs' outlets, disconnected by perpetually frozen grounds, each outlet is blocked up separately by excavation and its water is concentrated in one excavation in the lowest section.

During the operation of the spring for the arrangement of the principal concentrating well, in the center of the funnel of the thawed earth's layers one pumps the water out permanently and leads it away by means of gutters to a somewhat lower place beyond the funnel of the thawed earth's layers.

During the pumping fathoming is produced, as well as the measuring of the state of the horizons in the principal excavation and surrounding bores.

Test pumping is necessary by means of mechanical pumps. One must not lose sight of one thing: that at the beginning of the pumping the water yield is always more than that established later on in the operation.

ARTESIAN WATER

Artesian waters are streams shut in the thickness of alluvia, having in their upper part and foundations water resisting layers, which under well-known geological conditions form in the water hydrostatic stress (head).

Artesian water results from atmospheric moisture. Such cases of its formation can take place in the perpetually frozen grounds, but cases previously mentioned, i.e., cases of juvenile water formation, must be added to them. Artesian waters can be found only in comparatively young geological Jurassic and Tertiary systems of sediments, and in volcanic formations, accumulated during the Jurassic, Cretaceous and Tertiary periods.

Artesian water research is accompanied by a detailed geological inspection of the place and a deep boring.

To obtain artesian water one is obliged to study the layer and sometimes some layers of perpetually frozen grounds by means of boring. The temperature of the layers of perpetually frozen grounds comes up to -2°C . The temperature of artesian water in its water-carrying stratum comes up to $+3^{\circ}\text{C}$. This last circumstance does not prevent the water's penetration through the bore-hole and spontaneously risk freezing.

During the boring, after having passed the layer of perpetually frozen grounds and reached the water, it is necessary to guarantee

without delay rapid flowing of water through the borehole in order to enable warm water to warm the pipes of the borehole sufficiently and to thaw a certain part of the frozen ground surrounding the pipes.

It is also advisable to heat the borehole at the beginning of its work by steam, letting it in the borehole through pipes from the steam boiler.

Furthermore, during normal development of the borehole special heating measures are generally not required.

TECHNICAL RECORD

The construction of the water-supply and its operation can be done well only if in due time all the available technical data during the survey of the water supply and design of the plant are collected.

The technical record must be compounded of the following parts:

1. Description of the spring's character, of its site, of the origin of the constituent layers with illustrations: horizontal plans, profiles of geodesy-surveys, sections and photographs.

2. Description of the order and course of the work to determine the place of the spring's outlet and its concentration plant.

3. Description of the spring's yield (by means of flood-gate or pumping) with review of pumping, graphs of expenditure and water horizons of the pumping and observations on excavation and boring, as well as the results of the chemical analyses of water.

HYDROGRAPHIC AND METEOROLOGICAL SURVEYS FOR WATER SUPPLY

BY JAMES E. JONES

(Assistant Engineer in Charge of Hydrography, Aqueduct Division)

AND GEORGE A. LEWIS

(Hydrographer)

*(Bureau of Water Works and Supply, Department of Water and Power,
Los Angeles, Calif.)*

The water works engineer is faced with the necessity of having an assured supply of water for the community that he serves. Some cities have at their very doors a supply whose quantity is so great that potability is the only serious question; others must study methods to obtain volume, potability, accessibility and dependableness.

Western cities to a large number have limited water supplies, the limit being usually found in the lack of dependence that can be placed upon the supply during the periods of drought.

The growth of Southern California has taken place to a large extent, during a series of dry years and to obtain a knowledge of the local sources of water supply stream flow records were started about thirty-five years ago.

As the surface supply became less available for expansion recourse to underground sources became necessary; conservation of supply made a knowledge of what could be expected from precipitation a prerequisite to an intelligent estimate of future supply, when coupled with an understanding of the nature and extent of the operating losses in collection and distribution.

Records of precipitation at stations located at fairly regular distance intervals from Mono Lake to Los Angeles, also of temperatures, wind velocities and evaporation constitute the meteorological data regularly obtained by the Hydrographic Section of the Department of Water and Power of the City of Los Angeles.

The rainfall records are the more frequent in spacing, due to the

item of expense and more general interest of the coöperative assistants.

The records of temperatures, wind velocities and evaporation are kept at reservoirs sites and places where trained employees are stationed at all times.

The rainfall records, derived from about thirty stations, are principally located in the valleys, mountain records not being usually obtainable due to the absence of observers to care for the equipment.

The evaporation studies are made with either land or floating pans and date back on some stations for fourteen years, making a record which in conjunction with the precipitation record permits proper deduction from water available in estimating water that can be delivered; consideration being given also to other operating losses. The studies of the effects of variations in temperature, wind and precipitation upon evaporation from the reservoirs, and other areas, naturally lead to the effect of percolation from, and to, the same bodies of water. It has been found that during rising stages of reservoir operation, percolation into the beds is a large item, measurable only by computing the difference between inflow and the total outflow plus evaporation. This is often reversed and the percolation from the beds into the reservoirs is discovered by the same method. A knowledge of where the water goes is one of the great needs of the water works man.

The field covered by the operations of the Hydrographic Section embraces the measurement of the snowfall and rain, the discharge of the streams into the collecting system, the effect of climatic changes upon the supply and its delivery to the city, the losses in transit from the Sierra Nevada mountains, and ground water as an auxiliary supply; all for the single purpose that the water executive may be reasonably well informed as to how much water he has in storage, how much may be expected to become available during the season and from what sources, after making proper allowances for operating losses.

All water systems include storage, usually both surface and underground, and methods of measurement and systems of records are matters of common knowledge and practice.

The measurement of flowing waters is of such long standing study among water men that books dealing on practically every angle are now available outlining in fair detail the answer to any general question.

SNOW SURVEYS

The necessity for some definite knowledge of the value of the snow fields of the mountain area, expressed in comparable terms to that used for other water sources, became apparent in the operations of public service corporations and political subdivisions, and numerous separate systems were started to obtain the needed data. The territory capable of being covered by any one organization, at a reasonable expense, was too limited for best results and plans for coöperation were soon developed thus giving to all the advantage of the knowledge gained as to equipment, methods and data. The present extent of the coöperative efforts along this line is shown by the fact that at the meeting of the Western Interstate Snow Conference held in Berkeley on June 21, 1934, forty-three representatives were present from Utah, Nevada, Oregon, Washington and California, representing the states, cities, power companies and other organizations. Among those thus represented was the Department of Water and Power of the City of Los Angeles.

Snow surveying, or the determination of the water content of a snow cover, had its origin in Europe as a study of the physical characteristics. Later, in the eastern United States and the Sierra Nevada mountains its possibilities were realized as a means of forecasting stream flow for agricultural, power and domestic needs. The question of what supply will be available is of equal importance with that of flow or storage on hand.

In the summer of 1925 departmental employees visited Dr. J. E. Church in Reno, Nevada and discussed with him the plan and methods used by himself and associates in forecasting the runoff of the Truckee River Basin.

Dr. Church had developed the Mt. Rose Sampler tube and scale by which it is possible to obtain the depth of the snow and to bring up a core to be weighed in the scale and read thereon as inches of water. This enabled the survey to be made upon a basis comparable to rainfall records. As a result of this visit to Dr. Church and associates the present system of snow surveys was started in the winter of 1925-26 by the Hydrographic Section of the Owens River Aqueduct.

In conformity with the plan outlined by Dr. Church visits were made to the proposed snow survey courses prior to the winter fall of snow to obtain a preliminary view of the ground so as not to choose a line that was of unusually broken surface. The original courses

were located in Cottonwood Canyon, Big Pine Canyon, Rock Creek and Minarettes. To these have been added the Mammoth courses.

A system of snow surveys requires a group of fixed courses, located at selected points on the watershed where a series of measurements taken in the same spot each year gives a comparison by which future runoff may be predicted. To insure that each measurement is taken at the identical point each year the courses are surveyed, marked and mapped. A copy of this map is carried by the observers. Facilities for observers are provided by means of well stocked cabins in each of the various basins, as well as suitable clothing to protect them from inclement weather.

The field equipment comprises pack bags, sampling apparatus, and ski or snow shoes as a means of transportation when the snow fields are reached. Transportation to the snow field is by car, horses, dog teams, or if necessary even on foot by ski or snow shoes.

The Mt. Rose Sample tube consists of light steel tubing in short sections which may be coupled together in the field.

A field party consists of two, sometimes three, observers and the time required for a survey is two days or more, depending upon the location of the courses and the weather conditions. If possible enough parties are sent into the field to cover all basins at the same time.

Prior to the establishment of the snow surveys the Section had been obtaining a record of several years duration of the stream flow in the Owens Valley and was in the position of having data to establish normal runoff records for use in conjunction with the snow records to be obtained.

Two methods for forecasting have been developed, known as the area and the percentage methods. One seeks to determine the actual amount of water in acre feet over the entire area of the watershed, and the resulting runoff. The other attempts to ascertain the relationship of snow cover to the percent of normal runoff in the stream.

The use of any method must be modified by factors for soil absorption, temperature variations, and precipitation during runoff.

The use of the stream flow records enables a comparison to be made, on some streams dating back to 1904, setting up a relationship between the years of snow survey record and the longer more variable runoff period. This enables a valuation to be fixed upon the current data so that the estimates made will have as a basis the ratio of the present snow crop to those of former years as well as to the runoff

of the stream being studied. The method used by the Section has always been the percentage one, no exact determination of the acre feet of water in the snow fields being possible with the money and personnel available. The obtaining of a ratio, or percentage, between any two years, or series of years, enables a proportion to be set up with runoff as the other members of the equation. Usually the runoff season is the hydrographic year of October 1 to September 30, wherein the April survey is made during the middle of the year and the results therefor only being used to estimate the last half of the year.

Still using the original idea for its comparative value, a second plan is now used whereby a factor is obtained, that expresses the product of water-content and coverage, and plotted against runoff in second feet gives a curve for each snow course that enables the estimated discharge, as based upon that course, to be read directly in terms of second feet. The mean of all estimates made for the courses of a particular stream basin gives the estimated runoff for the station at which it is desired to know the supply.

The annual reduction of runoff and water content to long term averages, or so called normals, takes into account the changing values as the period of record lengthens.

The value of the estimates made increases with the length of record and experience in forecasting, as is shown by the following table:

YEAR	APRIL MEAN WATER CONTENT				PERCENT ACTUAL OF ESTIMATED RUNOFF	RUNOFF		NOTE
	Minaret		Mammoth			Actual	Estimate	
	8300	9000	8300	9500				
1927	23.28	36.00			73.7	356	483	a
1928	3.96	17.68			84.7	250	295	b
1929	10.28	18.21	8.93	20.06	83.0	206	248	b
1930	4.52	16.60	5.46	24.13	107.4	131	122	b
1931	5.37	10.97	6.27	15.54	102.6	79	77	b
1932	26.44	40.60	25.80	57.34	92.6	189	204	c
1933	14.20	23.20	14.50	31.58	111.8	161	144	c
1934	3.96	16.29	6.10	21.73				

(a) 7 month period SF. (b) 6 month period SF. (c) Mean annual SF.

The water content of the snow field is shown to vary from year to year and between the several survey courses, but this degree of

accuracy has been such that since, and including, 1930 the range has been about ten percent plus or minus. Due to the use of different runoff stations in making the annual estimate a comparison is not possible between the several years given in the runoff columns, and also due to the last two years being for the full hydrographic year instead of the shorter period formerly used. The effect of ground absorption from the snow fields, as indicated in the years 1932 and 1933 by the water content and runoff columns, may explain the discrepancy in the results of the estimate by being proof of the recharging of the soil in the year of heavy snow fall and its draining to some degree during the following drier year.

The last half of the hydrographic year is the season of low precipitation and high municipal uses, accompanied by heavy evaporation. It is the season that determines the degree of judgment and foresight of the water works executive, as in it he either will prove his judgment good by having a sufficient water supply in storage, or available from natural sources, or he will subject himself to public criticism by having to shut down on the less necessary uses. If by use of the snow surveys he has reason to believe sufficient runoff will occur from gravity sources of supply to take care of the anticipated demands, then the necessity for pumping from the underground supply need not be so seriously considered.

The replenishment of the underground supply in the Owens River drainage basin is being studied as a part of the runoff data, but that part directly attributable to snow cover has as yet not been set up as a separate study. It is believed that equipment such as would be required for soil absorption observations should only be put out where an observer would be regularly available, in making actual field observations, and due to the great variation in climatic conditions laboratory experiments do not seem justified because each section is a problem in itself.

The first man of record to attempt to forecast runoff is spoken of in the Bible in the book of Genesis and due to the lack of belief in the forecast the world was said to have been nearly depopulated. Several thousand years have passed since his efforts and methods and procedure are still being improved upon. Noah left very little record of his methods, but it is felt that the concerted efforts of many men in the western portion of the United States will develop this branch of water supply engineering to a point that the ordinary citizen will have faith and act according to its forecasts.

(Presented before the California Section meeting, October 26, 1934.)

ELIMINATION OF PITS AND SUBGROUND-LEVEL PUMPROOMS¹

BY O. E. BROWNELL

(Sanitary Engineer, State Department of Health, Minneapolis, Minn.)

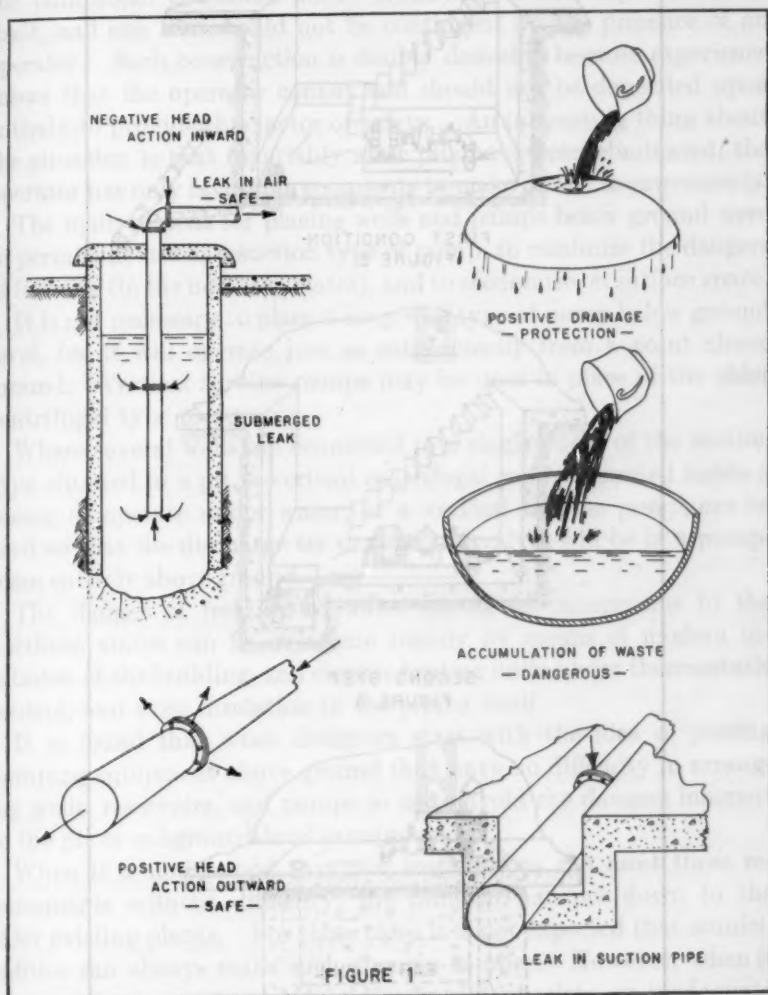
The practice of locating wells and pumping equipment in basements, subground-level pumphrooms, or specially constructed pits below ground surface has been followed for many years, and is, to a large extent, still being carried on. It has not been, and is not yet, generally understood that water supplies may become dangerously contaminated through conditions resulting from this type of construction. Consequently, suction pumps and piping and even deep-well pumps have been located in pumphrooms below ground.

Pits or subground-level pumphrooms become receptacles for the accumulation of waste water, and if leaks occur in a suction pipe or well casing which is situated in such pit or pumphroom, the contaminating waste water may be drawn into or gain access to the water supply. Experience shows that the special drainage systems which are a necessary adjunct of pit construction, cannot be relied upon, and sooner or later a pit or subground-level pumphroom will be flooded with sewage or contaminated water. Flood waters backing up through drains into pits, stoppage in drains, sump pumps that do not function properly, and broken pipings, all have, at one time or another, resulted in the flooding of well or pump pits. Flooded well pits have been involved in large epidemics of water-borne disease. The Mankato (1908) and the Benson (1917) epidemics in Minnesota are examples of the serious results of this type of construction.

When a pipe is under a negative head, the action of the forces is toward and into the pipe (figure 1). From a sanitary point of view, the combination of a suction pipe situated in a pit or subground-level pumphroom is one of the worst, for the flooded pit usually provides the contamination which will be drawn into the water supply if a leak occurs in the pipe. This identical arrangement caused the Benson epidemic (figure 2). The first step taken to correct this type

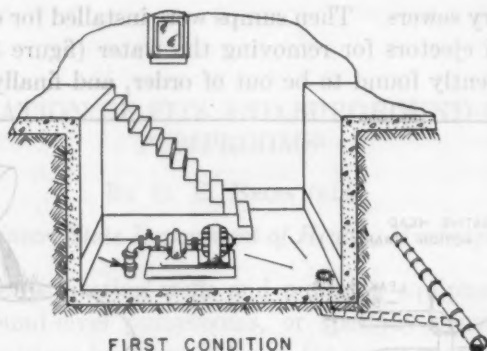
¹ Prepared for the Committee on Water Works Practice.

of construction was the removal of direct connections between pits and sanitary sewers. Then sumps were installed for collecting waste water, and ejectors for removing the water (figure 3). The latter were frequently found to be out of order, and finally only by elim-

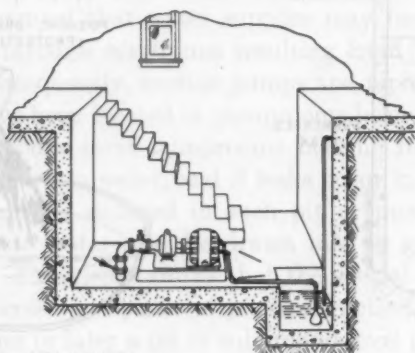


inating the pits entirely has flooding of wells and pumps been reduced to a negligible item.

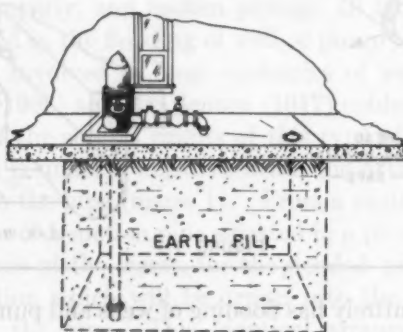
By extending the casing of a well to a point above ground level, by filling the surrounding pit with compact earth, and by placing the



FIRST CONDITION
FIGURE 2



SECOND STEP
FIGURE 3



FINAL CORRECTION
FIGURE 4

pump, discharge tee and valves above ground level, the possibility of flooding is practically removed (figure 4). Even though the same situation might exist for a pumproom above ground as would result in the flooding of a pit or a pumproom below ground, the fact that the pumproom is located above ground is an added protection in itself, and one that would not be contingent on the presence of an operator. Such construction is doubly desirable because experience shows that the operator cannot and should not be depended upon entirely to provide this factor of safety. An interesting thing about the situation is that invariably after pits have been eliminated, the operator has only favorable comments to make on the improvements.

The main reasons for placing wells and pumps below ground were to permit the use of a suction type of pump, to minimize the dangers of freezing (in the northern states), and to economize on surface space.

It is not necessary to place a deep-well type of pump below ground level, for it will operate just as satisfactorily from a point above ground. Vertical turbine pumps may be used in place of the older centrifugal type of pump.

Where several wells are connected to a single pump of the suction type situated in a pit, a vertical centrifugal pump mounted inside a casing to operate under water, or a vertical turbine pump, can be used so that the discharge tee or pipe and valves will be in a pumproom entirely above ground.

The danger of freezing of water piping in pumprooms in the northern states can be overcome readily by means of modern insulation of the building, and electric heating units under thermostatic control, and even insulation of the piping itself.

It is found that when designers start with the idea of placing pumping equipment above ground they have no difficulty in arranging wells, reservoirs, and pumps so as to avoid the dangers inherent to the pit or subground-level pumproom.

When it is understood that new installations can meet these requirements without difficulty, the problem narrows down to the older existing plants. For these cases it is not expected that municipalities can always make such changes at once. However, when it becomes necessary to replace old worn-out, obsolete, or inadequate equipment, advantage should be taken of this opportunity to eliminate the subground-level pumprooms and pits. Thus, if no more of this type of construction is installed and the existing installations are

corrected as rapidly as feasible, a workable program for the elimination of this dangerous feature from water supplies will be under way.

For example, in Minnesota since 1927, when it became a requirement of the State Board of Health to place pumping equipment above ground, 103 municipalities have eliminated pits and have placed all the pumping equipment above ground. Also, since that time, fifteen new water supplies have been installed which have complied with this requirement.

The requirements of the Minnesota Department of Health in regard to well pits, subground-level pumprooms and suction pipes are as follows:

"Pump Pits. Pump pits or subground-level pumprooms either drained directly to a sewer or provided with a sump-and-ejector apparatus are always subject to flooding, and are considered dangerous. Pits require special drainage systems which often get out of order. Leaks in the well casing at a time when the pit is flooded would permit contaminating material to get into the well. On account of the difficulty of maintaining such pits or pumprooms in dry, sanitary condition at all times, they are not considered as satisfactory as pumprooms situated entirely above ground.

"No wellhead, well casing, pump, pumping machinery, valve box connected with a suction pipe, or exposed suction pipe should be located in any pit, room, or space extending below ground level, or in any room or space above ground which is walled in or otherwise inclosed so that it does not have free drainage by gravity to the surface of the ground.

"Pumprooms. The pumproom floor should be at least six inches above the ground surface, and should be drained away from the well and drop pipe connection in all directions.

"There should be no pit or unfilled space below ground surface level any part of which is within eight feet of any well, spring, suction pipe, or like feature of any such water supply."

The Conference of State Sanitary Engineers, at its 1932 meeting held in October at Washington, D. C., went on record as opposed to well pits.

A standard practice regarding the locating of pumping equipment above ground level, if set up and recommended by the A. W. W. A., would be of considerable assistance to officials and engineers in constructing safer water supplies.

It would seem desirable to have a uniform practice as a guide in order to minimize the difficulties which designing engineers, material and pump manufacturers have in meeting standards in various sections, and also to avoid the embarrassment when the

standards of any organization, state, or city are compared with those of its neighbor.

In view of this situation, it is suggested that the A. W. W. A. investigate this problem with the view of setting up a recommended practice to be followed and included in the Manual of Water Works Practice.

DANGER OF CONTAMINATION OF WATER SUPPLY
WHEN WATER AND SEWER PIPES ARE
CLOSE TOGETHER¹

BY O. E. BROWNELL

(*Sanitary Engineer, State Department of Health, Minneapolis, Minn.*)

A review of the present day water works practice shows that most of the faulty types of construction which have been responsible for water-borne epidemics are no longer used. However, certain types of construction through which a water supply may become contaminated are still commonly used. Among these is the laying of water and sewer pipe very near each other or in the same trench. It has been found in some sections that this arrangement of piping is more prevalent than is generally supposed. As more information becomes available showing that relatively high vacuums lasting over considerable periods of time are created in water mains, (see paper on Cross Connections with Public Water Supplies in the JOURNAL OF THE AMERICAN WATER WORKS ASSOCIATION, 24: 11, page 1750, by S. B. Morris) the danger of this arrangement is apparent.

There are three typical conditions of this problem which deserve study, i.e.,

1. The laying of water pipe and sewer pipe parallel to each other in the same trench or in nearby trenches.
2. Water pipe and sewer pipe crossing each other at an angle, as at street intersections.
3. Water and sewer service pipes from the street mains or sewers into the property.

It is generally conceded that sewers as ordinarily constructed are not water-tight. There may be considerable leakage of sewage into the surrounding soil, and especially so if the sewer should be placed under pressure by stoppage or for other reasons, such as overloading. Under this condition, if a relatively high vacuum should occur in a nearby water pipe which had a leak in it, contamination

¹ Prepared for the Committee on Water Works Practice.

would probably be drawn into the water system. When breaks occur in water mains located near sewers, the escaping water may have sufficient force to break the sewer. Cases have been found where the water escaping from a leak in a water main finds its way through leaks into nearby sewers and is carried away without disturbing the earth covering or being discovered for some time. Actual instances of these conditions have occurred, as at Fairmount, North Dakota, in April, 1923, where an outbreak of typhoid fever resulted from leaks in water and sewer pipe laid close to each other when a negative head was produced in the water pipe.

The actual contamination of the water may take place as described above while the systems are in operation or in the process of making repairs after breaks in the pipes have occurred. In making the repairs the water is shut off, thereby removing the protection afforded by the pressure, and the trench or excavation containing both water and sewer pipe may become flooded with sewage, thus contaminating the water pipe. Nine cases of typhoid are supposed to have resulted from draining off leakage from a water pipe into a sewer at Wade-Location, near Kinney, Minnesota, in January, 1919. The sewer pipe became clogged and presumably the sewage backed up into the water pipe.

These conditions may occur at sewer- and water-pipe crossings in street intersections, and in service pipes leading from the street mains to the property.

Some of the questions involved in the problem are:

1. The character of the earth formations surrounding the pipes, as to its imperviousness, filtration abilities, stability, etc.
2. The strength and suitability of material and the construction of the pipe lines.
3. Safe distances both vertical and horizontal between pipe lines.

In the case of parallel water and sewer pipes, the Minnesota Department of Health requires that they be laid not nearer to each other than 8 feet. No qualification or differentiation is made depending upon various earth formations encountered. Obviously, 8 feet of creviced rock or coarse material does not have sufficient filtration ability to be of much protection. It is not practical to vary the distance between pipes necessitating changes in alignment as different materials are encountered. To avoid settlement of the pipes due to settling backfill in a trench, water pipes are often placed on a shelf to one side of the trench, and if possible, above the sewer.

This practice has some merit but cannot always be followed on account of grades and a depth of earth covering necessary to protect the water pipe against freezing. Such an arrangement is no insurance against the possibility of the water system becoming contaminated as described above. Water pipe placed above a sewer when near it is obviously in a safer position than when placed at the same level or below the sewer.

The Minnesota Department of Health has recommended that at street intersections "all that part of the sewer lying within 8 feet of the water pipe shall be constructed of cast-iron pipe with water-tight joints." In such cases the water pipe is safer when placed above the sewer; however, a sewer immediately under a water pipe may be more dangerous than a sewer 8 feet above the water pipe with good intervening earth material.

It seems nearly impossible to avoid many of these crossings, for unless property is served by water from the street and sewer from the alley, or vice versa, it is necessary for service pipes to cross mains.

Actual instances are known where water mains pass through man-holes of sanitary sewers, and we have reports of water pipes passing through sewers at an angle and also through cesspools.

Perhaps another question involved is brought up by the size and character of the pipe lines themselves. For instance, a large intercepting sewer carrying sewage even under pressure may have the power to affect structures a considerable distance from it. How close to such a sewer may a water pipe be placed, or what protective measures should be required in constructing the sewer?

This subject would seem to have importance enough to warrant a study and development of a standard of practice for the guidance of water-works designers and builders.

It is suggested that the following questions be studied:

1. Determination of the prevalence of the practice of placing water mains and sewer pipes in the same trench or near each other in the street, and also the same practice as to the service pipes from the street mains to the houses.
2. Effectiveness of different distances in various earth formations as filters or barriers to passage of bacteria. These values should be determined both for vertical and horizontal distances.
3. The various types of construction for both water pipe and sewers needed for protection where there is danger of infection of the water.

4. Street or piping layouts to avoid dangerous arrangements.

From these studies a standard of recommended minimum requirements may be developed.

5. Recommended ordinances regulating such construction.

It is recognized that perhaps little can be done to change existing conditions. However, in new installations, many of these defects can be avoided and so reduce the percentage of the total hazard which would otherwise be expanded by continuing the present practice as villages and cities grow in size. Changes in existing systems may present opportunities for correcting such conditions, and a standard practice on this question would be valuable as a guide.

MECHANICAL CLEANING OF WATER MAINS AT EVANSVILLE, INDIANA

BY CHARLES STREITHOF

(General Superintendent, Department of Water Works, Evansville, Ind.)

At the annual meeting of the Indiana Section of the American Water Works Association, held last year at Lafayette, Indiana, I had the honor and pleasure of presenting a paper entitled, "Inserting Gate Valves Under Pressure."

The valves had been inserted in some of the important mains at Evansville. At the time I read that paper, I also showed some pictures. Those pictures displayed sections of pipe, in sizes 6- to 30-inch diameter, the sections being those removed from the various mains, to be replaced by valves. Those of you who were present at last year's meeting may recall the pictures also showed plainly the true condition of the interior of the water mains.

Some of the sections were from 35 to 45 percent full of some kind of material, which proved to be hard blue mud. When the valve inserting job was completed, and having seen that the majority of our important mains were carrying but little more than half their capacity, I felt justified in asking our Board of Water Works Trustees for an appropriation, to start cleaning some of the mains. I was able to convince the Board of the necessity for, and the importance of, this work and as a result of some discussion it was decided to clean some of the larger and older mains. A contract was made with the National Water Main Cleaning Company of New York City, to clean the mains, as designated.

The work was started June 20, 1934, on 6000 feet of 16-inch pipe and was continued until the contract was completed. Under the contract a total of 37,956 feet of 12-, 16- and 20-inch mains were cleaned, and practically restored to their original carrying capacities. The results obtained were so gratifying and satisfactory, the Water Works Trustees were more than convinced of the advisability of continuing this excellent work, and made a second contract with the same company to clean all mains laid prior to filtration, from 10- to 30-inch, inclusive. The total footage of the second contract was

approximately 87,500 feet, and the results obtained were as good as, if not better than, those of the first contract. The Board of Trustees then decided it would be the wise and only thing to do, to clean all pipes laid prior to filtration, and on November 1, 1934, a third contract was made with the same company, for approximately 450,000 feet, which is represented principally by 6- and 8-inch pipe.

METHOD OF CLEANING

Work on this last contract is now in progress, when weather permits. The manner of operation is simple, yet most effective. When the size of pipe, and distance to be cleaned, are determined, the line is "killed" by closing two valves, one nearest the inlet for the entrance of the cleaning apparatus, and the other nearest the outlet. At the inlet end, the pipe is exposed and a piece of the main, about six feet long, is removed. This piece of pipe, if removed with a cutter, is cleaned by hand, the cleaning device, (sometimes called rabbit) is placed in it, and then returned permanently to the line by employing a sleeve and using the bell end of the existing pipe. At the outlet the line is also exposed, where a smaller piece is removed, depending on the diameter, so as to permit a 45 degree bend of the same size to be attached to the end of the line to be cleaned. This joint is made with yarn only. And to the 45 degree bend is added a short piece of pipe, jointed with yarn also, to bring the line up to, and a little above, the level of the street. Then the valves controlling the lines feeding off the one to be cleaned are closed, as are all curb cocks. It is now time to start the cleaning apparatus on its journey. The valve nearest the inlet is now opened. The water entering the dead line hits the cleaning machine and as the pressure and volume increase, the machine starts to move, and while there is no foreign obstruction in the line such as a partly closed valve, or large pieces of lead from a poorly poured joint, the machine will travel the entire length of the line to be cleaned, and drop on to the pavement at the outlet. The rate of travel is never alike in any two pipe lines of the same size and length. In cleaning 8257 feet of 30-inch pipe, the cleaning machine traveled at a speed of 60 feet per minute, and discharged 47 truck loads of mud, plus that which went into the sewers.

While the machine is moving, enough water is permitted to pass it to serve as wash water, which helps to reduce the pressure of the material ahead of the machine, and long before the appearance of

the machine, some of the obstructing material will be seen on the pavement. Almost from the moment the machine starts to move from the inlet end, until it is out of the main, the wash water which precedes it is very dirty. Immediately following the appearance of the machine at the outlet the water practically clears up, but it is advisable to permit the water to run a short time to thoroughly flush the line which has just been cleaned. When the machine has done its job, and the line has been flushed, it is a simple task to remove the makeup at the outlet, replace the piece of pipe there, open the valves which had "killed" the line and those controlling the side lines, and then open the curb cocks.

RESULTS

The results from main cleaning at Evansville were most gratifying. Velocity tests were run on various lines before cleaning, and the drop in pressure noted, as well as the discharge at the hydrants. The same hydrants were used after the mains were cleaned, and when readings were taken, the difference showed an increase of 15 to 35 percent more water. With only two hydrants discharging 1000 gallons per minute each, a drop of 2 to 4 pounds was noted, while before cleaning a drop of 6 to 15 pounds was common.

Operation at the main pumping station has been affected by the cleaning to such an extent that one ten million gallon pump is operated only 16 hours per day. The pump is shut down at 10 p.m. and started at 6 a.m. the next morning. The water used during the shut-down period is received from a twenty million gallon reservoir, which is able to furnish a 50 pound pressure.

The people of Evansville have been most interested and enthusiastic with the main cleaning program, considering the money well spent, for they realize, in addition to restoring the system to its original carrying capacity, which assures them of increased pressures and volumes, an ever present and dangerous fire hazard has been removed.

In addition, practically all the valves in the pipe lines were operated and tested, and those found defective were repaired or replaced. Therefore, the annual inspection of valves is not necessary on the lines which have been cleaned, as has been done in former years, thereby effecting a substantial saving to the Water Department.

(Presented before the Indiana Section meeting, March 8, 1935.)

WATER SUPPLY FOR CONSTRUCTION CAMPS

BY CLAYBURN C. ELDER

(Hydrographic Engineer, The Metropolitan Water District of Southern California, Los Angeles, Calif.)

The Colorado River Aqueduct project is now so well known to every one, in outline at least, that a general description hardly needs repetition here. A summary of its current status, however, may be of interest before proceeding in more detail with the camp water supply system.

Although a separate Federal project, the Boulder dam is fundamentally necessary for aqueduct operation, as a source of pumping power as well as a regulated water supply. Its rapid progress toward completion, nearly two years ahead of schedule, is therefore of quite as great importance to the District as that of any aqueduct structure. Assuming average reservoir inflow, it is now officially stated that power can, if needed, be made available for the aqueduct by April 15, 1937, giving at least a year's margin of safety in this vital matter.

Down the Colorado River 150 miles below the Boulder dam, at the Parker diversion dam site, actual construction is now under way. The contract for this unit of the aqueduct was awarded to the Six Companies, builders of Boulder dam, on Sept. 4, 1934, as a result of obtaining an allocation of \$2,000,000 from the Public Works Administration including a grant of \$500,000. It now appears probable that interstate litigation, which long threatened to delay the construction of this dam, has been successfully avoided.

TUNNELS

The main aqueduct tunnels have as yet received chief emphasis as regards actual construction, because these require longest to complete. The work was financed, at the end of 1932, by a \$40,000,000 bond purchase agreement by the Reconstruction Finance Corporation. Within the last week, the halfway mark was passed on excavation of the 92 miles of tunnel, 8 of the shorter ones having been completed, leaving 21 still being drilled from 47 headings. Speed records

have been established, such as 315 feet of gravel tunnel excavation in one week, 265 feet of hard-rock tunnel in a similar period, 54 feet of hard-rock tunnel in 24 hours (all from one heading only) and at Berdoo on the Coachella tunnel, with hard rock but considerable timbering, 2 $\frac{3}{4}$ miles completed from 2 headings in one year. Serious water troubles have been encountered on only 2 of the 29 tunnels. The worst has occurred on the 13-mile San Jacinto tunnel, where the 800-foot deep Potrero shaft was recently twice flooded, as a result of a water inflow estimated to have reached a maximum of 7,500 g.p.m. The shaft is now unwatered, however, with a uniform inflow of 2,000 g.p.m., and tunnel excavation is once more under way there after a delay of 4 months.

NEW CONSTRUCTION

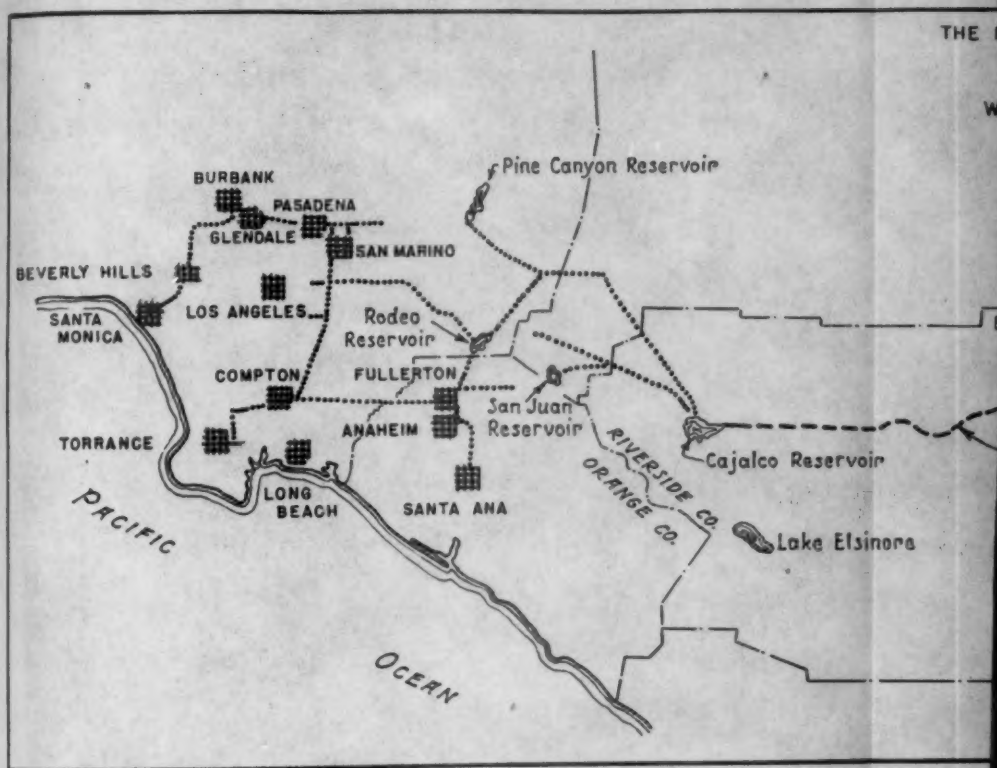
The Reconstruction Finance Corporation recently made an additional allotment of \$15,000,000 to the Metropolitan Water District, which enabled the District to award, on October 19, 1934, 4 year contracts for the construction of 110 miles of canals, conduits and siphons in 16 separate schedules amounting to approximately \$25,000,000. On October 31, bids will be opened for 30 miles of additional conduit and siphons and award of contracts for these schedules will put the entire main aqueduct under construction, from the Colorado River to the terminal Cajalco Reservoir. Work completed or then under way will exceed \$100,000,000 in estimated cost or about one-half of the probable total cost of the initial project. The chief remaining features are the 5 pumping plants and transmission lines, terminal and intermediate reservoirs, and also distribution pipe lines to the 13 member cities of the District. Actual expenditures to date on Aqueduct construction amount to approximately \$28,000,000, and Federal financing is available covering anticipated costs for about one year ahead. Present direct employment totals 4500 which, will be increased shortly by another 2000 men, as a result of the recent new contracts.

CONSTRUCTION UTILITIES

Before construction of the main aqueduct could begin, a relatively large amount of preliminary work was necessary installing camps and general utilities, because the aqueduct for most of its length crosses the desolate, previously uninhabited Colorado Desert. Only 5 to 10 years ago, when surveys and investigations were under way to

THE

W



THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
COLORADO RIVER AQUEDUCT

WATER SUPPLY FACILITIES DURING CONSTRUCTION

LEGEND

CONSTRUCTION WATER LINE ————
 DISTRIBUTION SYSTEM
 5 0 5 10 15
 SCALE OF MILES

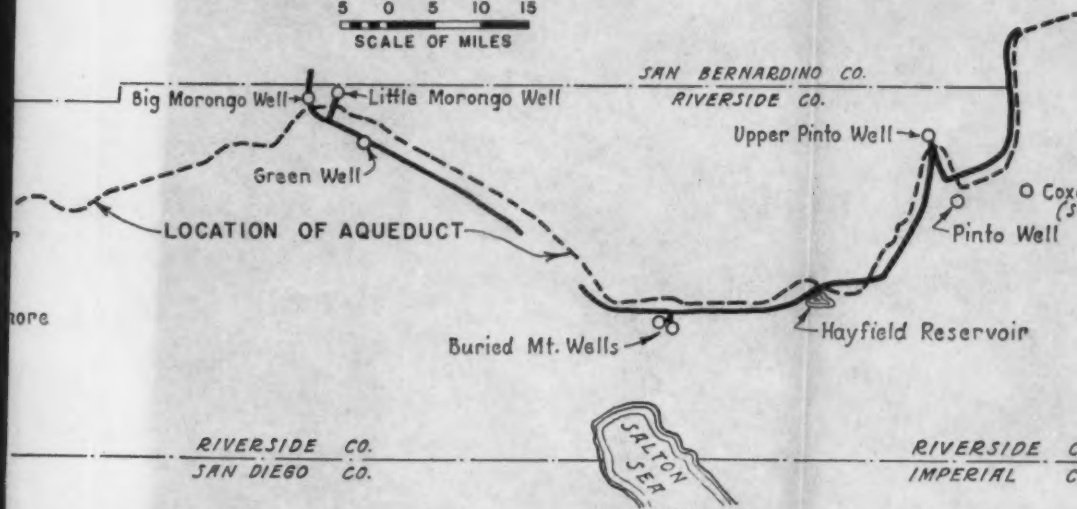
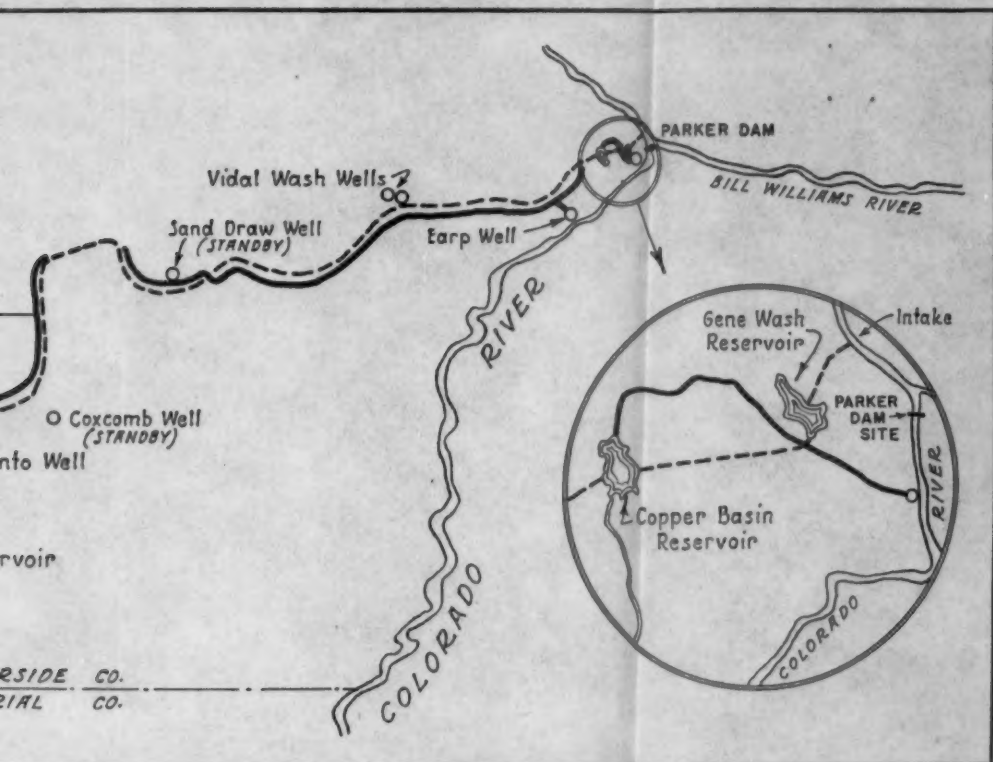


Fig. 1





determine the best aqueduct route, this was undoubtedly the most difficult and inaccessible large area then remaining in the United States. It could safely be crossed only by the occasional, long-acclimated, experienced prospector with pack burros, and water holes were few and far between even for them. Roads were the first necessity, and 150 miles of main paved highway have been built along the aqueduct line, in addition to utilizing State highways so far as possible. A somewhat greater mileage of secondary roads is also now in use, the total cost being over \$900,000. A special telephone system is giving fine service, with 1,050 miles of line and costing about \$300,000 to install. The construction power system, which incidentally furnishes all pumping power for the water system as well as for camp and construction purposes, includes 196 miles of 66,000-volt line and 274 miles of 33,000-volt line, with necessary switching and substations. Including these features and the camp water system, but not contractors' or District construction camps, a total of about \$4,000,000 has been expended on preliminary utilities, in preparation for the larger scale work now in progress.

During preliminary aqueduct surveys, it was generally possible to locate the small, temporary camps near some desert spring or well, because the quantities of water required were relatively small. Where necessary, water for camp use was hauled as much as 20 or even 30 miles from the nearest well. The quality was sometimes far from satisfactory especially in hot weather, but there was little complaint or dissatisfaction, for the field engineers of the Southwest and their assistants are necessarily tough and rather proud of it, and are far less accustomed to or insistent on even reasonable comforts than are the workmen who follow them to complete the job. For the latter, an ample supply of good water is essential, especially under extreme desert conditions.

GROUND WATER STUDIES

Because more than 100 possible aqueduct routes were under consideration and investigation, covering practically the entire southeastern sections of California and Nevada, between Yuma and the Boulder Canyon dam (and even east into Arizona, northeast into Utah and southward through Mexico) an intensive study of possible desert water supply sources was not practicable until the final aqueduct route was definitely adopted. All available records and reports were of course compiled, every rumor of springs or water holes was

eagerly seized upon, and observations were maintained on all springs and existing wells that seemed to have the remotest possibility of proving useful. Even after the Parker route was selected, however, and the aqueduct bonds voted, about 3 years ago, by their impressive 5 to 1 majority, immediate financing for the project was not available and much uncertainty existed as to when funds could be secured, due to what was by then rather prematurely considered to be a severe depression. It was therefore still not possible to squeeze into the budget a general campaign of exploratory well drilling, such as seemed essential, was clearly desirable, and would at least have been most interesting to all concerned with ground-water problems. This was doubtless in part because it was almost unanimously assumed, even or perhaps especially by those fairly familiar with the desert and who had long suffered from heat and thirst there, that for the camps along the first 100 or 150 miles of the aqueduct line, water must necessarily be piped from the Colorado River, and pumped up a 2,000-foot lift from the lower Coachella Valley for most of the other camps. The somewhat optimistic belief of our most confirmed "desert rats" that ample and good water could be found at various points in the Sahara-like Colorado Desert was quite reasonably pronounced a "pipedream" of the dizziest variety. For even a hazel twig water witcher might well hesitate to practise his art in that region.

DRILLING OF WELLS

But without any such divining aid, a start on well drilling was made early in 1932 with three 10-inch wells in the driest stretch of the desert to the north and east of the quite accurately-named Desert Center. The results were not very promising for later success and none of these wells is actually connected to the present water system. One gave a large flow at shallow depths but far too salty for domestic or general construction use, and deeper exploration failed to find any water-bearing stratum of better quality. The well has been heavily pumped, however, for road construction purposes. The other two wells are available for standby use if required and were also pumped during the road building period, but one proved of rather variable and undependable quality. The third early well, ample as to quantity and of good quality, is at a relatively low elevation on the Pinto Wash, and its regular use was made even less economical by a subsequent change of location of the Coxcomb Mt. tunnel, the well now

being below and at a considerable distance from the aqueduct line. These unused wells are here referred to in some detail to avoid giving the impression, which would be quite misleading and inaccurate, that drilling good water wells in the Colorado Desert is a simple, easy or certain affair. Several 6-inch test holes were also drilled, the evidence from these being largely negative or disappointing in character.

About two years ago the \$40,000,000 allotment of Reconstruction Finance Corporation funds suddenly made possible the immediate commencement of aqueduct construction, this being the very first of the thousands of such nationwide Federal public works loans that have since issued from the Reconstruction Finance Corporation and more recently from the Public Works Administration. The need for additional camp water supply sources was at once acute, as the design of the water system and preparation of plans and specifications were practically impossible until the chief sources were determined. Rigs were at once put to work in the difficult, central section of the aqueduct route, at the most hopeful points as indicated by topography and the somewhat scanty geological and ground-water data that were by then available. Good producing wells, now the main sources for the water system, were obtained at each of the 3 chief sites, although only after the usual difficulties that seem unavoidable in drilling deep wells, particularly in untested areas. Fifteen miles east of Mecca, and about 5 miles above Shaver's Well, at the Buried Mt. well No. 4, for example, the tools became stuck after rapid progress had been made to within a few feet of the estimated water level. Meanwhile, the deadline rapidly approached when a contract must be awarded for a pipeline from Indio, bids having actually been opened for a water supply from the lower Coachella Valley. Finally, with but one day's leeway, a 200 g.p.m. well with excellent water was brought in, and the long pipe line and high lift from Indio were made unnecessary. An equally successful companion well near the same point is now also being regularly pumped.

Difficulties were likewise met in the case of the Upper Pinto Well No. 8, about 20 miles by aqueduct roads north of Desert Center. These roads were practically impassable at the time, especially for a heavy well rig, which promptly became hopelessly stuck in sand drifts as soon as it turned off the aqueduct line road toward the designated well site, 2 miles further upgrade across the trackless desert. As the need for haste was great, and the District "water

witch" was temporarily out of sight, a hole was drilled just where the rig became stationary, on the reasonable theory that there was where a well would be most appreciated, anyway. The sad result was a dustar nearly 800 feet deep, with finally about 25 g.p.m. of hot, salty water to show for all the trouble. A superhuman effort was then made and the rig moved nearly to the right spot, but a shallow, dry hole into lava rock forced a further counsel-of-war. A final move was agreed on, to the spot originally fixed by ground-water theory and "instinct," (the field surveyors by then being somewhat in despair) and at a depth of less than 100-feet, a flow of 750 g.p.m. or more of fine, soft water was struck, doubtless to the pleased surprise of the "water witch" concerned, who will admit under pressure that the happy result was to some extent a lucky coincidence.

At Vidal Wash, 7 miles northwest of the town of Vidal, the chief difficulty encountered has been the fine sand in the water-bearing stratum, which has since forced the installation of gravel envelope wells in order to secure uninterrupted operation. Two such wells there are now producing 100 g.p.m. each, which to that extent reduces the amount to be pumped from the Colorado River, 15 miles away and with a static water level 330 feet lower. Several shallow wells along the river bank supply all requirements east of Vidal, such wells being much cheaper and more satisfactory than to attempt to clarify the river water. The quality of water obtained from such river wells varies surprisingly, even when but a short distance apart, and it has been found necessary to locate these wells as close to the river as is safe from flooding, to get a water of reasonably low salt contents. With flood control now provided by Boulder Canyon Reservoir, however, no serious difficulty is anticipated on this account.

Water for the western portion of the Coachella tunnel is obtained from shallow, dug wells in the mouths of Big and Little Morongo Canyons, at the north end of Coachella Valley. These wells are supplemented by a pipe line down the Big Morongo Canyon leading from springs and artesian wells in Morongo Valley, and also by a ranch well in Seven Palms Valley, above the Mission fault line, made temporarily available by its owner for aqueduct use. Further west, from Whitewater River across the San Jacinto Mountains and Perris Valley, as well as along the Valverde Tunnel line to Cajalco Reservoir, ample water supplies from many different sources are obtainable with relatively little difficulty, and contractors on these

sections of the aqueduct provide their own camp and construction water supplies.

East of Coachella Tunnel, however, such a method would have been entirely impracticable, as the aqueduct contracts are for relatively short schedules and contractors would have been forced to compete against each other for the limited local supplies. Much duplication of wells and pipe lines would also have been unavoidable, and such higher costs and the many uncertainties involved would have been obviously reflected in the aqueduct bids. Under the existing arrangement, water is guaranteed to the tunnel contractors

TABLE 1

Data on wells and well-pumping equipment on construction water supply system

NO.	LOCATION	GROUND ELEV.	DEPTH OF WELL	DEPTH TO WATER	TEST	TOTAL SOLIDS	HARDNESS	PUMPING EQUIPMENT		
								Oper. Head	Pump Cap.	Pump
			feet	feet	g. p. m.			feet	g. p. m.	h. p.
1	Big Morongo	1,788	26	15	350	955	430	62	375	15
2	Little Morongo	1,618	70	56	400	850	472	124	350	20
3	Green Well	1,045	187	137	110	895	96	206	150	15
4	Buried Mt. (E.)	1,320	555	244	190	345	104	400	300	50
5	Buried Mt. (W.)	1,350	536	266	210	465	155	442	200	40
7	Pinto (lower)	682	452	181	450	615	47	Not equipped		
8B	Pinto (upper)	1,045	547	97	410	545	17	160	750	40
13	Vidal	960	785	266	100	600	59	530	150	30
14	Vidal	958	629	267	90	610	55	530	150	30
15	Earp	369	93	11	340	640	378	90	300	10
16	Eureka Wash	381	103	17	450	1,095	403	60	600	15

at 15 cents per 100 cubic feet (a rate of 30 cents per 100 cubic feet has more recently been fixed for the new conduit and canal contracts) so that at least one of the major uncertainties of desert construction work was definitely removed. Detailed data for the various wells, the 12 deep-well pumps, and 36 booster pumps equipped with electric motors and automatic controls are shown in table 1. The connected load amounts to 2,500 H.P., of which 1,000 H.P. is for standby purposes.

PIPE LINES

The distribution system consists of four separate units, as dictated by topographical conditions and the limitations of the described

sources of supply. The western section extends from the Morongo wells to Berdoo Camp, where the pipe line is discontinued because the rough topography there forces the grade down to elevation 700, about 1,000 feet below the aqueduct grade, and even lower elevations would have been required further east. The dependable yield of the available wells is only sufficient for the camps from Berdoo westward.

The central section, from Fargo Camp to the west portal of Iron Mountain Tunnel, is 79 miles in length, being supplied from the fortunately-situated Buried Mountain and Pinto wells. Because no satisfactory supply was obtainable in the basin between the Iron and Coxcomb Mountains, this section of the pipe line had to be laid over the Coxcomb range, which involves considerable booster pumping but permits service further east by gravity.

The eastern section, from the Iron Mountain tunnel to the Colorado River at Earp (opposite Parker, Arizona) supplies 70 miles of aqueduct work and obtains water from the Sand Draw, Vidal Wash, and Earp wells. The short river section extends from the Eureka Wash well, near the Parker dam site, up into the Whipple Mountains, supplying the Colorado River, Copper Basin, and east portal of the Whipple Mountain tunnels.

The distribution pipe lines were designed on the basis of the following unit demands:

	gallons
Camps, per man per day.....	100.0
Compressors, per 1,000 cubic feet of free air.....	0.67
Tunnel drills, per drill per day.....	167.0
Mixing concrete, per cubic yard.....	40.0
Washing aggregate per cubic yard—net loss.....	48.0
Subgrade wetting, 1 inch depth on area covered	

Additional allowances were made for miscellaneous uses and waste, and as a further margin of safety, the system was designed to supply the maximum estimated daily demand in 16 hours of pumping. No specific allowance was made for concrete curing water, as curing will in general be effected by other means, but ample water is available for such water curing as may be found desirable.

The system is made up of 180 miles of 5-, 6-, and 8-inch light-weight welded steel gas-line pipe, with branch lines of 3- and 4-inch sizes as required. Except at drainage crossings and over rocky sections, the line is laid in trench with an 18-inch minimum cover. No expansion joints are provided, but the pipe was purposely looped or

laid crooked in the trench, providing slack to take care of expansion and contraction. Where laid on the surface, the pipe was bent or sprung in a lateral arc between the anchors, the arc being supported on skids or smooth ground to permit movement under changing temperatures. The latter are extreme, varying from freezing or slightly below to a recorded maximum of 127 degrees in the shade, of which there is absolutely none along this pipe line.

TABLE 2
Water consumption, Colorado river aqueduct

MONTH ENDING	NUMBER MEN IN CAMP SERVED	WATER CON- SUMPTION, MIL- LION GALLONS	PER CAPITA CON- SUMPTION, GAL- LONS PER DAY
July 16, 1933.....	1,410	3.0	68
August 16, 1933.....	1,600	5.24	105
September 15, 1933.....	1,830	7.06	129
October 16, 1933.....	2,120	5.83	89
November 15, 1933.....	2,580	8.45	109
December 16, 1933.....	2,530	8.55	109
January 16, 1934.....	2,570	8.30	104
February 14, 1934.....	2,780	9.90	123
March 16, 1934.....	2,900	10.15	116
April 15, 1934.....	3,120	14.62	156
May 16, 1934.....	3,150	15.30	157
June 15, 1934.....	3,200	17.45	182
July 16, 1934.....	3,250	16.45	163
August 16, 1934.....	3,390	16.95	162
September 15, 1934.....	3,330	17.07	171
October 16, 1934.....	3,290	15.41	151

Annual mean, 144 gallons consumed daily.

STORAGE

Storage is provided by six 300,000-gallon gunited reservoirs and four 300,000-gallon bolted steel tanks located at strategic points along the system. The gunited reservoirs are of circular shape, 15 feet in depth and with top and bottom diameters of 88 and 40 feet, respectively. Some of the reservoirs float on the line, while others are used as storage between the well pumps and main-line booster pumps.

Of the District's 9 Coachella tunnel camps, 5 are served by piston displacement-type pumps and the remainder by multistage centri-

fugal pumps, all electric motor driven and automatically controlled. Ten thousand gallon tanks floating on the line feed the pumps and camps are served by gravity from 65,000-gallon tanks.

WATER CONSUMPTION

Water for each user is delivered from the pipe lines under sufficient pressure to fill a tank at about the delivery point elevation. Each

TABLE 3

Booster pumping stations

NO.	BOOSTER STATION	RATED CAPACITY	OPERAT- ING HEAD	MAXIMUM LENGTH DELIVERY LINE	NUMBER PUMPS	PUMP STAGES	PUMP
		<i>g. p. m.</i>	<i>feet</i>	<i>feet</i>			<i>h. p.</i>
1		250	325	22,000	2	4	40
2		140	400	27,000	2	4	40
3	(West)	240	400	40,300	1	4	50
	(West)	240	400	40,300	1	3	50
	(East)	200	730	39,200	2	6	75
4		180	720	38,600	2	6	75
5	(West)	300	600	44,600	2	4	75
	(East)	260	600	24,400	2	4	75
6		170	690	2,000	2	6	75
7		150	360	44,600	2	6	25
8		180	400	65,400	2	4	40
9		220	360	50,000	2	4	40
10		260	460	46,000	2	6	50
11		240	460	86,100	2	4	50
12		240	800	22,700	2	2	100
13		110	550	16,000	2	5	50
14		260	720	14,000	2	6	100
	Green	150	300	5,000	1	2	25
	Sand Draw	150	200	4,000	1	2	15
	Buried Mtn.	250	325	5,000	2	4	40
		4190		637,200*	36		1090

* Equal to 120 miles.

outlet is provided with water meter, strainer, by-pass, throttling cock, and pressure-reducing regulator where necessary. Deliveries are limited to 50 g.p.m. per outlet and each user furnishes his own receiving tank and booster pump if required. Water consumption by months during the past year is listed in table 2 for all camps from Morongo to the Colorado River. For the twelve month period end-

ing October 16, 1934, total consumption was 158,000,000 gallons, with an average daily per capita consumption (including all construction uses) of 144 gallons. The water consumed, with the tunnels now half excavated, amounts to 930 gals. per foot of tunnel drilled, equivalent to 65 percent of the hydraulic cross-sectional area of the completed 16 feet tunnels. By the time these are lined, the tunnel construction water used will probably exceed their total volume. For the month of maximum water use, as yet experienced, with a per capita daily use of 182 gallons, the total metered water consumption amounted to 23 per cent of the maximum designed capacity of the system, based on a 16-hour pumping day.

WATER TREATMENT

At the time the wells for the construction water system were developed, general analyses were made which indicated that the waters could be used without softening or other treatment being necessary, the regularly pumped supplies being of fair to good quality, by Southwestern desert standards, at least. However, in about three months' time, trouble with "red water" became a major problem. This eventually appeared in all portions of the system except that section served by the Buried Mountain Wells. Investigation disclosed that the causes of this "red water" were: (a) Excess free carbon dioxide; (b) *Crenothrix*, an iron bacterium; (c) sulfate reducing bacteria; and (d) excess iron in the natural well waters. The sections affected showed evidence of one or more of the causes in varying degree.

Upon the advice of Carl Wilson, Consulting Water Technologist for the District, aerators, chlorinators, and dry lime feeders were installed as required along the entire system. At Big Morongo and Little Morongo aerators were constructed to remove the free carbon dioxide and a chlorinator was installed at Big Morongo as a sanitary measure to treat the surface flow from the Morongo Valley, use of which has been forced by the drouth. No treating equipment has been required as yet for the Buried Mountain section. To eliminate the excess iron and sulfate-reducing bacteria, an aerator, chlorinator, and dry-lime feeder have been installed at the Pinto Well. Likewise, at the Vidal Wells, a chlorinator and dry-lime feeder have been found to be necessary, and will shortly be installed there, with water conditions fairly similar to those at the Earp and Eureka Wash Wells, where the same equipment is already in use.

TABLE 4
Chemical analyses of water from the Metropolitan Water District construction water supply wells in active service

Well Number	HIG MO- RONGO SURFACE FLOW 4/10/34	1	2	3	4	5	8B	13	15	17	PARKER SUBSTA- TION 3/15/34
Name	HIG MO- RONGO 6/20/34	LITTLE MO- RONGO 6/20/34	GREEN 4/16/34	BURIED MTN. 6/20/34	BURIED MTN. 6/20/34	PINTO 1/19/34	VIDAL WASH 9/17/34	EARP 3/15/34	EUREKA WASH 6/19/34		
Date of Sample											
Gravimetric analysis, expressed in parts per million											
Calcium (Ca)	94	105	35	22	49	7	22	102	104	63	
Magnesium (Mg)	28	51	2	12	8	0	1	30	35	39	
Sodium (Na)	65	114	265	94	106	192	187	77	228	217	
Carbonate (HCO ₃)	0	0	0	0	0	0	0	0	0	0	
Bicarbonate (HCO ₃)	348	337	52	244	168	104	65	174	232	326	
Chloride (Cl)	20	40	104	32	56	112	122	118	201	186	
Sulphate (SO ₄)	170	373	465	61	162	185	230	227	410	249	
Total hardness as CaCO ₃	350	472	96	104	155	17.5	59	378	403	317	
Alkalinity as CaCO ₃	285	276	43	200	138		53	142	190	267	
Total salines, approximate	550	850	895	345	465	545	600	640	1,095	915	
Reacting values, expressed as milligram equivalents											
Calcium (rCa)	4.6906	4.4910	1.7465	1.0978	2.4451	0.3493	1.0978	5.0898	5.1896	3.1437	
Magnesium (rMg)	2.3016	4.1100	0.1644	0.9864	0.6576	0.0	0.0822	2.4660	2.8770	3.2058	
Sodium (rMg)	2.8275	7.4820	4.9590	11.5275	4.6110	8.3520	8.1345	3.3495	9.9180	9.4395	
Carbonate (rCO ₃)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Bicarbonate (rHCO ₃)	5.7072	6.3632	0.8528	4.0016	2.7552	1.7056	1.0660	2.8536	3.8048	5.3464	
Chloride (rCl)	0.5640	1.2408	2.9328	0.9024	1.5792	3.1584	3.4408	3.3276	5.6682	5.2452	
Sulphate (rSO ₄)	3.5360	8.4656	9.6720	1.2688	3.3696	3.8480	4.7840	4.7216	8.5280	5.1792	
Concentration value	19.62	32.16	26.90	12.32	15.42	17.40	18.60	21.80	36.00	31.54	

Character formula, expressed in percent

Calcium (rCa).....	23.90	13.96	18.21	6.50	8.85	15.82	2.01	5.86	23.35	14.41	9.97
Magnesium (rMg).....	11.72	12.78	14.56	0.63	7.95	4.29	0.0	0.43	11.28	8.00	10.14
Sodium (rNa).....	14.38	23.26	17.23	42.87	33.20	29.89	47.99	43.71	15.37	27.59	29.89
Carbonate (rCO ₃).....	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate (rHCO ₃).....	29.10	19.80	19.18	3.16	32.47	17.90	9.78	5.75	13.07	10.55	16.95
Chloride (rCl).....	2.85	3.85	3.89	10.89	7.30	10.24	18.10	18.50	15.27	15.75	16.63
Sulphate (rSO ₄).....	18.05	26.35	26.93	35.95	10.23	21.86	22.12	25.75	21.66	23.70	16.42

Groups, expressed in percent

Alkalies.....	14.38	23.26	17.23	42.87	33.20	29.89	47.99	43.71	15.34	27.59	29.89
Alkaline earths.....	35.62	26.74	32.77	7.13	16.80	20.11	2.01	6.29	34.63	22.41	20.11
Weak acids.....	29.10	19.80	19.18	3.16	32.47	17.90	9.78	5.75	13.07	10.55	16.95
Strong acids.....	20.90	30.20	30.82	46.84	17.53	32.10	40.22	44.25	36.93	39.45	33.05

Chemical properties, expressed in percent

Primary salinity.....	28.76	46.52	34.46	85.74	35.06	59.78	80.44	87.42	30.74	55.18	59.78
Secondary salinity.....	13.04	13.88	27.18	7.94	0.0	4.42	0.0	1.08	43.12	23.72	6.32
Primary alkalinity.....	0.0	0.0	0.0	0.0	31.34	0.0	15.54	0.0	0.0	0.0	0.0
Secondary alkalinity.....	58.20	39.60	38.36	6.32	33.60	35.80	4.02	11.5	26.14	21.10	33.90
Hydrogen ion, pH.....	8.0	7.7	8.0	7.9	8.2	8.1	7.7	7.7	8.0	8.2	8.0

In spite of desert heat and long pipe lines, the treating equipment is operating very satisfactorily. The major "red water" troubles have been eliminated. In some cases the pipes still contain crenothrix and some sulfate reducers, together with excess corrosion. These bacteria are being disposed of by sterilization of mains, and after operating for a time with the present noncorrosive waters, all discoloration caused by excess corrosion will undoubtedly disappear.

The water system is periodically inspected by a supervisor with a crew of five patrolmen, whose duty it is to check the operation of equipment, to oil motors, pumps and bearings, change flow-meter charts, ink pens and wind clocks weekly, read water meters monthly, clean and chlorinate reservoirs, tanks and pipe-lines when necessary, and make any adjustments or repairs as may be required.

The complete construction water system has proved to be of ample capacity and has presented no major operation or maintenance difficulties. Its total cost is approximately \$830,000, or less than 0.5 per cent of the estimated cost of the work involved. This investment will largely, if not entirely, be offset by credits from water sales during the 6-year aqueduct construction period.

(Presented before the California Section meeting, October 26, 1934.)

CORROSION FROM ZERO SOFTENED WATERS

BY RAY L. DERBY

(Assistant Sanitary Engineer, Bureau of Water Works and Supply,
Los Angeles, Calif.)

The zeolite process of water softening has been known for many years and in wide use commercially in this country for over a score. The process for use in domestic installations, however, is much more recent. On the Pacific Coast, by far the greater number of such installations have been made within the past decade.

In the majority of these installations, little or no attempt was made to obtain a thorough knowledge or analysis of the water to be softened. Generally, it was merely considered sufficient that the total hardness and volume of water to be treated be known. Because of the many obvious advantages of soft water, especially zeolite softened, probably little thought was given to any possible disadvantages. In fact, what possible disadvantages could zero soft water have? Scale was not formed and a suds or lather could readily be obtained so what more could one ask?

If any consideration at all was given to the possibility of corrosion, it was most likely pushed aside as being unlikely if not impossible. All available data on corrosion indicated that little fear need be felt in waters with a pH greater than 7.0 and it was known that zeolite zero softened waters exceeded this. In fact, in the City of Los Angeles zero softening will raise the pH a full degree such as from 7.2 to 8.2 in cold water and nearly double that in hot water. In one case in particular, a raw water pH of 7.4 or 7.6 was increased to 9.6+ in the hot water.

Yet with all the many points in its favor, zero soft water has proved to be not an unmixed blessing. Corrosion has occurred which, on the evidence available, can be traced to no other cause than water softened to zero hardness. Mr. A. S. Behrman (1), Chemical Director, International Filter Company, makes this definite statement: "The fact remains that a zeolite softened water is a potentially corrosive water, the corrosive tendencies of which must be recognized and if possible corrected." Mr. C. P. Hoover (2), the father of

water softening, also states that: "Zero softened water when pumped through a distribution system is apt to be unsatisfactory because of red water troubles. This is especially true in the case of hot water heaters."

Within the past two years many cases of corroded piping and damaged hot water heaters have come directly to the Los Angeles Department of Water and Power and numerous others have been referred to us by plumbers. These cases consist of all classes of installations from residences to office buildings, hotels, hospitals, clubs and department stores. In all these, residence or commercial, it is nearly always the same story. The boiler of the hot water heater first fails, springing a leak in several places. This may happen once or more before the piping in the building is affected. In one case a heater boiler was replaced three times in five years. The hot water piping is next affected, generally at the joints, and at times the cold water lines show corrosion at couplings, tees, ells, etc. The metal shows a brownish white deposit and is readily punctured by any semi-sharp instrument such as a screw driver. The metal under this deposit is of a greenish black color, and in the case of boilers show innumerable flat pits or craters from $\frac{1}{4}$ - to $\frac{1}{2}$ -inch in diameter. The metal in these pits may be easily punctured by a key or other hard object. In one case a boiler had the appearance of having been riddled by shot and in another instance a float in a hot water storage tank had the same appearance. Galvanized metal, both pipes and boilers, shows greater damage than plain black iron or brass or copper pipe. However, iron to brass or other metal connections are very seriously affected as are joints between galvanized pipe and fittings. In one hospital the steam return lines from radiators, steam sterilizers and the like were badly damaged, horizontal runs being principally affected.

The one thing all these cases had in common was a water softener ahead of the damaged water heater or damaged pipe and the water was softened to zero hardness in all cases. The obvious cause would seem to be the water of zero hardness.

Some may wish to blame electrolysis for this corrosion. It is most certainly not of the stray current type, since in such cases damage is confined to points of contact where the current enters or leaves the pipe. In the examples observed, corrosion occurred and holes were eaten through pipes or joints at points where there was no possible contact.

Local electrolysis between the different metals of the pipe and coating or fitting seems a more likely cause. A hard water is generally a highly mineralized water and zeolite softening increases the mineralization more or less, thus increasing its capacity as an electrolyte. Zinc and iron in the case of galvanized pipe, or iron and brass or zinc, iron and brass joints present ideal conditions for this local electrolytic action to be set up. Even if all pipe and fittings are galvanized, the cutting of pipe threads or occurrence of pinholes in the coating due to poor galvanizing will expose the iron and thus permit action to proceed.

Iron, copper and brass are relatively unaffected by an alkaline medium if of not too great a pH. However, zinc is much more sensitive and has been considerably affected by a pH of 9.0, particularly in hot water. Inasmuch as the zero softened water is usually above pH 8.2 and sometimes even greater than 9.6 in hot waters, the galvanizing, particularly in hot water heater boilers, may be readily eaten through, the iron base exposed and local electrolytic action proceed from there. The galvanizing on ice cans in an ice plant was completely removed when a zeolite softened water with a pH of 9.8 was used. The can water was subsequently lime softened to a pH 8.0 and the galvanizing lasted much longer.

Dissolved gases may also play considerable part in corrosion. Oxygen, present in the raw water from 50 to 90 percent of saturation, may be forced out of solution by the increased temperature and thus attack any exposed metal available. Carbon dioxide will not be found in an uncombined state with a pH above 8.2, but the sodium carbonate or bicarbonate present may be broken up by the heat and CO_2 liberated. Decomposition might even go so far as to form sodium hydroxide and cause caustic embrittlement, although this action requires both a rather high concentration of sodium carbonate and high temperature such as would occur in a steam boiler, rather than hot water boilers. These possible ill effects may be offset by increasing the calcium to sodium ratio. A condition of saturation with a calcium carbonate, or supersaturation for high sodium content is most satisfactory for corrosion prevention.

REMEDIAL MEASURES

Since the apparent causes of this corrosion are exposed metal and local electrolysis due to different metals in contact in a rather highly mineralized alkaline solution, the remedies are obvious. First,

eliminate all but one kind of metal for pipe and fittings wherever possible. This means to stick to all black iron or all copper pipe and fittings. Galvanized pipe and fittings are not considered satisfactory due to this weakness in alkaline solutions and the fact of two metals exposed and in contact at all joints.

As for the exposed metal of the pipe, fittings, or boilers, the most effective method is to coat them with a thin film of a protective coating such as calcium carbonate. The simplest and most practical manner of doing this is to by-pass a certain amount of raw water so that the treated water contains approximately two to three grains of hardness. Behrman (1) and Hoover (2) both suggest this method. Chester Smith (3) suggests a water saturated or slightly supersaturated with calcium carbonate. In other words, a water containing a residual of some 20 to 35 p.p.m. of calcium carbonate is considered necessary for the proper chemical balance to prevent corrosion.

If there is a tendency for the pipes to accumulate excess scale or "lime up" badly because of using harder water, it is only necessary to shut off the by-pass and use zero softened water for a few days to remedy this condition.

This method of by-passing appears to be entirely satisfactory from our experience in Los Angeles. This remedy is recommended in all cases that come to our attention and so far, in those that have been followed up, corrosion seems to have been entirely arrested. The worst case recorded was that of a new office building only a year or so old. The hot water boiler and piping were in a surprising state of corrosion for such a short period of use. A by-pass was installed and after some six or eight months of operation there has been no evidence of further corrosion.

(Presented before the California Section meeting, October 26, 1934.)

REFERENCES

- (1) BEHRMAN, A. S.: Discussion of "Water Softening by Zeolite," Jour. Amer. Water Works Assoc., 24: 9, p. 1388, 1932.
- (2) HOOVER, C. P.: "Laboratory Control for Water Works," Jour. Amer. Water Works Assoc., 25: 9, p. 1285, 1933.
- (3) SMITH, CHESTER: "Corrosion After Purification Processes," Jour. Amer. Water Works Assoc., 25: 6, p. 820, 1933.

PRACTICAL ASPECTS OF COAGULATION WITH FERRIC CHLORIDE

BY CHARLES GILMAN HYDE

*(Professor of Sanitary Engineering, University of California,
Berkeley, Calif.)*

Any comprehensive discussion of the practical aspects of the employment of any coagulant used in water or sewage treatment, or in the arts, should presumably consider at least the following matters: the chemical and physical nature of the substance; its behavior as a coagulant; its availability and extent of use; its purchase, delivery and storage; its proper application; the production and conditioning of the floc; its effect upon and efficiency in sedimentation and filtration; the general character of the effluent of a suitable treatment plant utilizing the particular coagulant in question.

It is obvious that in the fifteen minutes allotted to the presentation of this paper, these matters can be touched upon only in very superficial fashion.

The use of the ferric coagulants, directly as such,¹ in water and sewage treatment is very recent. Ferric chloride is not mentioned as a utilized or usable substance in any of the text or reference books published in America to date, in either of the fields just mentioned. The available literature on the subject is scanty and is confined to technical journals and reports. In these it is virtually limited to the last three years. What literature is available deals almost wholly with the technical rather than the practical aspects of the use of this coagulant.

As noted hereinafter ferric chloride has been adopted as a coagulant at several water treatment plants in California, particularly in the Los Angeles district. A visit to these plants will demonstrate many of "the practical aspects of coagulation with ferric chloride" far more effectively than they can be described in this paper. Those interested in this matter should not fail to see the remarkable results being achieved with respect to color removal at the Wilmington

¹ Note subsequent reference to ferrous sulphate (copperas).

plant of the Los Angeles Department of Water and Power and of color and hydrogen sulphide removal, in conjunction with softening, at the two municipal water treatment plants of the City of Beverly Hills.

HISTORY OF USE OF FERRIC CHLORIDE

Ferric chloride, as a chemical substance, has been known for a very long time. Nearly 50 years ago Remsen (1) stated that "the simplest way to make a solution of the ferric compound (chloride) is to dissolve iron in hydrochloric acid and pass chlorine into it to complete saturation." Anhydrous ferric chloride was obtained at that time by heating iron wire in dry chlorine gas.

For a considerable term of years it has been recognized that ferric compounds, under favorable conditions, could be effectively utilized to produce coagulum or floc for the removal of turbidity and/or color from natural waters. It is only very recently, however, that they have become commercially available, in quantity and price, to compete with other coagulants, such as aluminum sulphate.

In July, 1898, at Quincy, Illinois, W. B. Bull (2) was the first to employ ferrous sulphate (copperas) as a coagulant. The ferrous sulphate was made by burning sulphur, passing the resulting SO_2 gas into water, and the derived sulphurous acid over scrap iron. In 1903 (3) ferrous sulphate was placed upon the market by the American Steel and Wire Company of Chicago, Illinois, for use in their so-called "lime and iron process" of water purification. Ferrous sulphate was and is available in large quantities at low cost as a by-product of the steel industry. By 1912, or in less than 10 years' time, nearly one hundred water purification plants are said to have adopted the process. Copperas may be considered as a ferric coagulant since it is invariably employed with lime and coagulation occurs after oxidation to the ferric condition.

In 1902 Duyk employed ferric chloride in a so-called "Ferro-chlor Process" at Middlekerke, Belgium (4).

In 1910, W. B. Bull (5) appears to have been the first to make and use ferric chloride experimentally as a coagulant in water purification. He produced FeCl_3 by treating scrap iron with gaseous chlorine obtained directly from an electrolytic cell. This work was performed at Chicago, Illinois, and at Toledo, Ohio.

In 1926, F. W. Mohlman and J. R. Palmer (6), at Chicago, Illinois, produced chlorinated copperas, a combination of ferric sulphate and

ferric chloride, by passing chlorine gas into a solution of ferrous sulphate. Their experiments were directed at the conditioning (coagulation) of sewage sludge. Since that time chlorinated copperas has been adopted as a coagulant at a number of water treatment plants in the United States, particularly where soft, colored waters are utilized as water supply sources.

In 1930, ferric chloride, in both solution and solid form, became commercially available in the United States. In that year manufacture on an adequate scale was begun both in the East and in California. Very recently (1934) anhydrous ferric chloride of practically 100 percent strength has been placed upon the Eastern United States market.

In 1931, ferric sulphate in dry form was placed on the market in Eastern United States.

During the last four years, since it has become available in California, ferric chloride has been adopted as a sludge conditioner at one sewage treatment plant (Pasadena activated sludge plant, 1930) and at several municipal and industrial water treatment plants. Among the municipal plants are the following: Antioch; Beverly Hills, two plants; Wilmington, Los Angeles Water and Power Department; San Diego, three plants; Lennox, American States Water Service Corporation. It has also been adopted as a coagulant at a number of industrial water treatment plants.

NATURE OF THE CHEMICAL, FeCl_3 . (7)

Ferric chloride, also known as iron chloride, chloride of iron, and iron perchloride, is available in three forms: anhydrous, solid or lump, and aqueous solution. Each form may be obtained in three grades: C.P., U.S.P., and Technical, the last being the common commercial grade as used, for instance, in water and sewage treatment.

Solid or lump ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) theoretically contains 60 percent active FeCl_3 and 40 percent water of crystallization. As ordinarily obtained the content of available FeCl_3 ranges between 58 and 59 percent. It is densely crystalline in structure, is yellow to brown in color, and is readily soluble in water, alcohol and certain other organic solvents. It is extremely hygroscopic or deliquescent and will gradually become liquid by absorption of moisture from the air. It must therefore be shipped and stored in air tight containers and used promptly after removal therefrom.

The physical data for solid ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) are as follows:

Specific gravity.....	1.632 (Franz)
Weight per cubic foot (unbroken).....	101.8 lbs.
Weight per cubic foot (lumps).....	$54 \pm$ lbs.* $58.5 \pm \dagger$
Melting point.....	$37^\circ\text{C. (98.6}^\circ\text{F.)}$
Solubility in water at $0^\circ\text{C. (32}^\circ\text{F.)}$	2.46 lbs. per lb. H_2O = 100 lbs. in 4.9 gal. H_2O
Content of FeCl_2	Not over 0.5 percent

* As determined from sizes of 100 lb. and 350 lb. drums in which lump ferric chloride is shipped.

† As determined from net weight shipped in 55-gallon casks.

Aqueous solutions of ferric chloride are dark brown in color and are made up to meet specific conditions. The clear settled liquor should contain less than 0.5 percent of FeCl_2 and not over 0.5 percent SO_3 .

To reduce the cost of transportation to the lowest possible terms the highest possible concentrations must be employed. The freezing or congealing point of the solution varies with the concentration. It is therefore necessary to adjust the strength of the solution to the temperature which may be expected to obtain during transit. A definite factor of safety must be provided. In order to avoid crystallization in transit, certain concentrations have been accepted as safe for temperatures as follows: between 30° and 60°F. , 40 to 46 percent FeCl_3 , varying 2 percent for each 10°F. ; between -20° and $+30^\circ\text{F.}$, 35 to 39 percent, varying 1 percent for each 10°F. In California, shipments of FeCl_3 carry the following percentages of available ferric chloride according to the season: in summer, 46 to 50 percent; in spring and fall, 44 to 46 percent; in winter, 43 to 44 percent. For the climate of northeastern United States, it is stated (7) that over the course of a year the proper concentration to meet weather conditions will average 40 percent FeCl_3 and that this figure can safely be used to estimate average transportation costs. To compute storage capacities the minimum concentration likely to obtain with respect to shipments should be used. In cold climates this may be as low as 35 percent. To compute pressures and pumping heads the weight of maximum concentrations, from 45 percent to 50 percent, as the case may be, should be taken into account.

Figures of density, specific gravity and strength of aqueous ferric chloride solutions at $20^\circ\text{C. (68}^\circ\text{F.)}$, computed from values published

in "International Critical Tables of Numerical Data" (*Physics, Chemistry and Technology*, vol. III, p. 68, 1928) are presented in table 1.

Actually the density and corresponding strength of an aqueous solution containing any stated percentage by weight of ferric chloride will vary slightly with the temperature. In table 2 figures are pre-

TABLE 1

Density, specific gravity and strength of aqueous solutions containing stated percentages by weight of ferric chloride (C.P.) at 20°C. (68°F.)

PERCENT FeCl ₃	DEGREE BAUMÉ	SPECIFIC GRAVITY	WEIGHT LBS. PER CU. FT.	WEIGHT LBS. PER GALLON	AVAILABLE FeCl ₃			
					Grams per liter	Lbs. per cu. ft.	Lbs. per gallon	Grains per gallon
1	1.0	1.007	62.8	8.40	10.07	0.629	0.084	590
2	2.1	1.015	63.3	8.46	20.30	1.267	0.169	1,190
4	4.5	1.032	64.4	8.61	41.28	2.577	0.344	2,410
6	6.8	1.049	65.5	8.75	62.94	3.929	0.525	3,680
8	9.1	1.067	66.6	8.90	85.36	5.329	0.712	4,990
10	11.4	1.085	67.7	9.05	108.5	6.773	0.906	6,340
12	13.7	1.104	68.9	9.21	132.5	8.270	1.106	7,740
14	15.9	1.123	70.1	9.37	157.2	9.815	1.312	9,180
16	18.0	1.142	71.3	9.52	182.7	11.41	1.525	10,700
18	20.2	1.162	72.5	9.69	209.2	13.06	1.745	12,200
20	22.3	1.182	73.8	9.86	236.4	14.76	1.973	13,800
25	27.5	1.234	77.0	10.29	308.5	19.26	2.574	18,000
30	32.7	1.291	80.6	10.77	387.3	24.18	3.232	22,600
35	37.8	1.353	84.4	11.28	473.6	29.56	3.952	27,700
40	42.7	1.418	88.5	11.83	567.2	35.41	4.733	33,100
45	47.4	1.485	92.7	12.38	668.3	41.72	5.577	39,000
50	51.5	1.551	96.8	12.94	775.5	48.41	6.472	45,300

sented to show the densities and strengths, in terms of grams per liter and grains per gallon, of aqueous solutions containing from 1 to 50 percent by weight of chemically pure ferric chloride for seven different temperatures between 0°C. (32°F.) and 35°C. (95°F.). In this connection it should be noted that the ferric chloride content of ferric chloride solutions is usually from 1 to 1.5 percent less than the

TABLE 2

Specific gravity (density) and corresponding strength in terms of grams per liter and grains per gallon of aqueous solutions containing stated percents by weight of ferric chloride, C.P., at various stated temperatures

PERCENT BY WEIGHT	TEMP. = 0°C. (32°F.)			TEMP. = 10°C. (50°F.)			TEMP. = 15°C. (59°F.)			TEMP. = 20°C. (68°F.)			TEMP. = 25°C. (77°F.)			TEMP. = 30°C. (86°F.)			TEMP. = 35°C. (95°F.)		
	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.	Specific Gravity	Grams per Liter	Grains per Gal.
1	1.009	10.1	590	1.008	10.1	590	1.007	10.1	590	1.005	10.0	580	1.004	10.0	580	1.002	10.0	580	1.002	10.0	580
2	1.017	20.3	1,190	1.017	20.3	1,190	1.016	20.3	1,190	1.015	20.3	1,190	1.014	20.3	1,190	1.011	20.2	1,180	1.011	20.2	1,180
4	1.035	41.4	2,420	1.034	41.4	2,420	1.034	41.3	2,410	1.032	41.3	2,410	1.031	41.2	2,410	1.029	41.2	2,410	1.027	41.1	2,400
6	1.052	63.1	3,690	1.051	63.1	3,690	1.050	63.0	3,680	1.049	63.0	3,680	1.048	62.9	3,670	1.046	62.8	3,670	1.044	62.6	3,660
8	1.070	85.6	5,000	1.069	85.5	4,990	1.068	85.4	4,990	1.067	85.4	4,990	1.065	85.2	4,980	1.064	85.1	4,970	1.062	84.9	4,960
10	1.090	109.0	6,370	1.088	108.8	6,360	1.087	108.7	6,350	1.085	108.5	6,340	1.084	108.4	6,330	1.082	108.2	6,320	1.080	108.0	6,310
12	1.109	133.1	7,780	1.107	132.9	7,760	1.106	132.7	7,750	1.104	132.5	7,740	1.102	132.3	7,730	1.101	132.1	7,720	1.099	131.9	7,710
14	1.128	157.9	9,220	1.126	157.6	9,210	1.124	157.4	9,200	1.123	157.2	9,180	1.121	157.0	9,170	1.120	156.7	9,150	1.118	156.5	9,140
16	1.148	183.6	10,700	1.145	183.2	10,700	1.143	182.9	10,700	1.142	182.7	10,700	1.140	182.4	10,700	1.139	182.2	10,600	1.137	181.9	10,600
18	1.167	210.1	12,300	1.164	209.6	12,200	1.163	209.4	12,200	1.162	209.1	12,200	1.160	208.8	12,200	1.159	208.5	12,200	1.157	208.2	12,200
20	1.187	237.4	13,900	1.185	236.9	13,800	1.183	236.7	13,800	1.182	236.4	13,800	1.180	236.1	13,800	1.179	235.7	13,800	1.177	235.3	13,700
25	1.240	310.0	18,100	1.238	309.5	18,100	1.236	309.0	18,100	1.234	308.5	18,000	1.232	308.0	18,000	1.229	307.2	17,900	1.226	306.5	17,900
30	1.297	389.1	22,700	1.295	388.5	22,700	1.294	388.0	22,700	1.291	387.3	22,600	1.288	386.6	22,600	1.285	385.5	22,500	1.282	384.6	22,500
35	1.360	476.2	27,800	1.358	475.3	27,800	1.356	474.4	27,700	1.353	473.6	27,700	1.350	472.7	27,600	1.348	471.6	27,600	1.345	470.8	27,500
40	1.428	571.2	33,400	1.424	569.4	33,300	1.420	568.2	33,300	1.418	567.0	33,100	1.414	565.8	33,100	1.412	564.6	33,000	1.408	563.4	32,900
45				1.492	671.4	39,200	1.488	669.8	39,100	1.485	668.3	39,000									
50				1.561	780.5	45,600	1.556	778.0	45,500	1.551	775.5	45,300									

Note. The values herein given have been calculated from values given in International Critical Tables of Numerical Data (*Physics, Chemistry and Technology*, vol. III, p. 68, 1928, National Research Council, McGraw-Hill Pub. Co., New York, N. Y.). Coöperating expert, Walter C. Schumb. The FeCl_3 content of commercial ferric chloride solutions is usually from 1 to 1.5 percent less than that of C.P. material for which the above table has been prepared. This is particularly true for the higher concentrations. The difference decreases on dilution in proportion to the amount or extent thereof.

1 Gram per liter = 58.42 grains per gallon. 1 Grain per gallon = 17.1 parts per million = 143 pounds per million gallons. To obtain parts per million from grams per liter multiply by 1000 = milligrams per liter.

strength indicated in tables 1 and 2 for chemically pure material. This is particularly true at the higher concentrations. The difference decreases on dilution and in proportion to the extent or amount thereof.

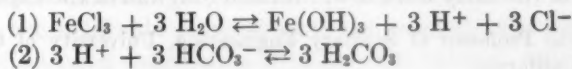
As a practical matter temperature effects can be neglected unless extreme accuracy is demanded for dosing or other purposes. In such case both the temperature and purity of the material will require to be known.

Tables 1 and 2 can be readily employed to determine the volume of solution of any given strength which must be added to a known volume of water in order to achieve the correct dosage either in parts per million or grains per gallon.

Ferric chloride solutions are extremely corrosive. No ordinary metals can be used successfully in contact with them, but there are certain of the newer iron alloys, such as Durichlor and Hastelloy "C" which, it is reported, can be employed with satisfaction. The solutions must be stored, pumped, mixed and transported in non-metallic things or in things made of such alloys as have just been named. The most available materials, according to the service required, are hard and soft rubber, stoneware, glass, protected concrete, wood, Haveg and the alloys of iron as suggested above. Certain asphalts or asphaltic preparations and certain rubber compounds, such as latex, are resistant to corrosion by ferric chloride and can be employed for waterproofing concrete and wood tanks. Strong ferric chloride solutions (say above 5 percent) are decidedly astringent. They will cause wood to shrink. Therefore, if wood containers are employed and are exposed to the direct action of strong ferric chloride solutions, arrangements must be made whereby the structure, whatever it is, can be tightened up from time to time as occasion requires.

CHEMISTRY OF COAGULATION WITH FERRIC CHLORIDE

When ferric chloride is added to water it hydrolyzes to form ferric hydroxide and release hydrogen and chloride ions. The hydrogen combines with the bicarbonate ion to form slightly ionized carbonic acid. The chloride ion remains in the water. The reactions may be expressed as follows:



No two waters are exactly alike or behave precisely similarly as respects coagulation. All authorities agree that, among other things, floc formation with any coagulant is related to the hydrogen ion concentration in the water and that the economic control is determined, at least in part, by the pH value. Other factors in coagulation are the electrical charges on the colloid particles in the water, the character of the electrolyte, the extent and kind of buffer salts present, the amount and character of the particles causing turbidity, etc.

Professor W. F. Langelier² was perhaps the first investigator to call attention to the importance of hydrogen ion concentration as a factor in the effective coagulation of water. His experiments were begun in 1919. In collaboration with the writer in the design of the water treatment plant for the City of Sacramento, Professor Langelier conducted elaborate studies aimed at the determination of the best possible procedure to adopt for the coagulation of the occasionally turbid Sacramento River water. In reporting this work in 1921 he states (8):

One of the most important observations that has been made in connection with these studies is the part played by the "reaction" of the water, or what chemists term "hydrogen ion concentration." Aluminum hydroxide is least soluble, and consequently most quickly and completely precipitated, in a medium the reaction of which is close to neutrality. . . . With water low in CO₂ the dosage of alum necessary to produce approximate neutrality is the amount that will reduce the alkalinity one-fifth. Therefore, if the alkalinity of the water is low, the alum necessary to raise the hydrogen ion concentration to approximately true neutrality, and thereby induce rapid coagulation and precipitation, is correspondingly low. It is apparent, then, that more often an acid, rather than a base, should be employed as a means of inducing rapid coagulation with alum. It would appear, moreover, from an extensive series of observations that we must revise our ideas in regard to the desirability of a "basic" alum.

In order to protect his discoveries from commercial exploitation, Professor Langelier applied for U. S. letters patent, the filing being made on February 25, 1920. Pursuant to this application, Patent No. 1,465,137 was granted on August 14, 1923.

Although the present discussion is not proposed to be comprehensive or critical, it would be inexcusably incomplete were mention not made of the early work of J. Morison (8a) and of the experimental

² Associate Professor of Sanitary Engineering, University of California, Berkeley, California.

studies and masterly survey of the entire problem by Wolman and Hannan, whose paper was entitled "Residual Aluminum Compounds in Water Filter Effluents" (8b).

As early as 1916 Morison made the important discovery that in the coagulation of water there is an optimum dosage with aluminum sulphate below and above which inferior results are obtained. He noted that the optimum dosage, for the particular water under investigation, was one which neutralized one-half of the alkalinity. The neutralization of one-half of the alkalinity would yield an approximately constant hydrogen ion concentration, a fact which he appears not to have recognized.

As early as December, 1920, Wolman and Hannan conducted laboratory studies to demonstrate what effect, if any, the pH value of a given water might have upon coagulation. In their paper the literature of the subject was critically reviewed to that date and the valuable results of their noteworthy experiment were recorded.

In the clarification of water by ferric salts, as with aluminum salts, there are three chemical factors which determine the optimum conditions for floc formation. Lewis B. Miller (9) states these as follows:

- (1) There must be present in the water a certain minimum quantity of ferric ion.

- (2) There must be present an anion of strong coagulating power, such as the sulfate ion.

- (3) The hydron concentration must be properly adjusted.

Bartow, Black and Sansbury (10) note that waters vary greatly with respect to optimum floc formation. The point of optimum coagulation may be as low as pH 3.8 in the case of highly colored soft swamp waters, or it may be greater than pH 8.0 with other waters. They state that the pH range within which good flocs may be rapidly formed is occasionally quite narrow and that in some cases the pH values must be adjusted closely.

These same authors conducted a comprehensive series of experiments on the formation of floc by ferric coagulants. They recognized the fact that natural waters contain varying quantities of sulphate ion, chloride ion, sodium ion, calcium ion, etc. An experimental determination of the effect of these ions on the formation of floc with ferric salts at different pH values seemed to show that:

1. On the acid side of neutrality the sulphate ion has a much greater effect upon coagulation than does the chloride ion.

2. Little difference, however, in the effect produced is to be noted with large variations in sulphate ion varying from 25 p.p.m. to 250 p.p.m.

3. The zone between pH 6.5 and pH 8.5 is one in which ferric floc forms slowly, or not at all.

4. In and beyond this zone, on the alkaline side of neutrality, sodium and calcium ions are most effective in coagulation.

They attempt to explain the zone of no floc or slow floc formation on the ground that a change may occur in the sign of the colloidal ferric floc from positive, on the acid side, where it is most affected by sulphate and chloride ions, to negative, on the alkaline side, where sodium and calcium ions become more effective in producing floc.

E. L. Bean (11) points out, however, that while under certain specific conditions there may be a zone of greatly delayed floc formation with ferric salts, some waters may actually have optimum pH values, as related to floc formation, within that same range or zone. Thus Ventre (12) reports a water in which optimum coagulation occurred at pH 8.5. There is evidence that ferric coagulation can be successfully applied over a pH range extending from 3.8 to 10.0, or even higher.

It is now generally recognized, following the pioneer work of Miller (13), Saville, and others, that stable (not coagulated) coloring matter in natural waters bears a negative charge. The "color" is said to be a typical negatively charged colloid. Color removal is probably more often effected by the neutralization of the negatively charged color colloid by the positively charged tri-valent ferric (or aluminum) ions than it is by the true ferric (or aluminum) hydroxide floc.

Ferric chloride has been employed with success in the treatment of water containing hydrogen sulphide in appreciable amounts. In contrast with alum, ferric chloride is an oxidizing agent. In treating waters containing reducing substances, such as hydrogen sulphide, the iron will be reduced from the ferric to the ferrous condition. It will then behave like ferrous sulphate in the "lime and iron" process. In order to be reoxidized to the ferric condition, a high pH value in the presence of additional air (oxygen) is necessary. This can be secured by the use of lime plus air as in the so-called "lime and iron" process previously referred to.

The reactions involved in coagulation, Willcomb (14) observes, are almost instantaneous and a colloid floc is formed at once which is

almost indiscernible to the naked eye. The problem presented is to increase the size of the floc particles to effective dimensions by coalescence.

As a practical matter it must be realized that waters vary greatly in their composition and characteristics. Each is more or less a problem unto itself and must be made the subject of careful study and experiment to determine the best and most effective method of clarification and/or decolorization. These methods may require to be changed from time to time to meet changing seasonal and other conditions. Viewed from the standpoints of both cost and performance, it must be recognized that no coagulant is or can be a panacea for all circumstances and conditions. The most effective chemical and the most effective use of that chemical must be determined by experiment and experience for each controlling condition.

BEHAVIOR OF FeCl_3 AS A COAGULANT

To an increasing extent, ferric salts are being utilized as coagulants or electrolytes for the removal of turbidity and color from water. These salts are: (1) ferric chloride; (2) ferric sulphate; (3) chlorinated copperas, essentially a combination of (1) and (2) in the proportion of 28.9 parts by weight of the former to 71.1 parts of the latter. In terms of iron (Fe), these values become 33.3 and 66.7, respectively. Craig and Bean (15), basing their conclusions upon plant scale experiments with all three coagulants, have determined that they may be used interchangeably and that when compared on the basis of equal iron content there is less than 10 percent difference in their respective performances. This general conclusion has been borne out by laboratory experiments conducted by R. A. Stevenson.

In comparison with aluminum hydroxide (true alum floc) all observers agree that ferric hydroxide has a higher specific gravity and requires shorter subsidence or settling basin retention periods for equivalent efficiencies in the removal of turbidity. The specific gravity of aluminum hydroxide is 2.4 while that of ferric hydroxide is 3.6 (7). Based upon their molecular weights, for equivalent numbers of Al and Fe ions, these values would be about 2.5 and 3.4, respectively.

Miller (16) states that ferric floc forms at a lower pH value than does alum floc, that it does not redissolve at the higher pH values as does the latter, and that therefore the pH range for effective floc formation is the greater with ferric salts. In consequence less careful

adjustment of the hydrogen ion concentration is required with the ferric coagulants, particularly in the higher and lower pH ranges.

Acidities such as are encountered with some soft, highly colored swamp or peaty waters make coagulation with alum impossible, because at pH values less than 5.4 alum floc will redissolve. However, such waters are amenable to successful coagulation (flocculation) with ferric compounds. In so far as organic colloids are concerned, it may be concluded that ferric coagulants are superior to alum. This is well attested by the experience at Wilmington (Los Angeles), California, Elizabeth City, North Carolina, and elsewhere. In this connection Hedgepeth and Olsen (17) assert that the "color floc," so-called, produced at low pH values by the action of trivalent ferric ion on the negatively charged color colloids, has adsorptive capacities far superior to those of true ferric hydroxide floc. In treating at Pontianak a water deficient in salts, containing from 1.7 to 2.9 p.p.m. of iron, having an approximate color of 2000° on the platinum scale and a pH value ranging from 2.9 to 4.2, Mom and Van der Hout (18) found that ferric chloride gave markedly better results than did alum or other ferric salts. When using alum with a water so poor in salts the pH value had to be held down to 6.0 since at higher values the aluminum would remain in solution as an aluminate.

Nolte and Kramer (19) state that low residual iron results from the use of all ferric coagulants and that this residual metal is less than the residual aluminum found when salts of the latter metal are employed.

Where the removal of manganese is necessary, ferric coagulants are particularly useful. Manganese cannot be removed except at pH values too high for aluminum salts, because alum is an amphoteric substance and the alum floc will redissolve at such high pH values. Ferric floc, on the other hand, is insoluble at all pH values.

Inasmuch as this paper is intended to discuss the practical aspects of coagulation with ferric chloride, it may be of interest to recite briefly some of the results which have been obtained by the use of this particular salt.

At Beverly Hills, in October, 1931, Stevenson (20) and Perhab made a comparison of the use of lime and alum and lime and ferric chloride at the Foothill Water Filtration Plant (Plant no. 2). The water treated at this plant is derived from wells and has a total hardness of about 200 p.p.m. It contains some hydrogen sulphide. The plant is a modern softening and filtration plant of 3 m.g.d.

capacity. With the use of lime and alum too much lime passed to the filters shortening the runs. With the use of lime and ferric chloride the bottom of the final settling basin became plainly visible at a point approximately 65 percent of its length measured from the inlet end, and within a few days the filter runs were increased 16 percent in duration. The filtered water was said to be sparklingly clear at all times and free from color and dissolved iron. The time required for the formation of the ferric floc was stated to be less than one-half that required with alum. The weight of ferric chloride (stated in terms of anhydrous FeCl_3) used was about one-half the weight of commercial alum formerly employed.

Ferric chloride coagulation was introduced at the La Cienega Water Purification Plant (Plant no. 1) at Beverly Hills in 1932. The water treated at this plant is derived from wells. It has a total hardness of from 150 to 200 p.p.m. and contains various amounts of H_2S depending upon the particular wells which are in service. This plant is also a modern softening and filtration plant and has a maximum daily capacity of about 7.5 mg. The use of ferric chloride there has produced similar results to those obtained at Plant no. 2. The average reduction in hardness has been 16 p.p.m. per grain per gallon of lime added to the water in conjunction with ferric chloride as compared with 15.1 p.p.m. with lime and alum. For equivalent results in the settling basins, when 8.0 grains per gallon of lime were used, the required dosage of ferric chloride (as anhydrous salt) was 0.5 g.p.g. as compared with 1.2 g.p.g. of alum. The cost of the chemicals themselves has not been widely different since the cost per ton of ferric chloride (available) has been twice that of the commercial, presumably 17 percent, alum formerly employed. The use of ferric chloride in the place of alum has, however, greatly hastened and improved clarification; has reduced hardness, with a given dosage of lime, to a greater extent; has lengthened filter runs; and has effected a saving estimated at 25 cents per ton in the handling costs of chemicals after delivery to the plant. Less storage space is required with ferric chloride and some saving in electrical power has resulted.

At the Wilmington filtration plant of the Department of Water and Power at Los Angeles, the use of ferric chloride has produced remarkable results in the reduction of color. This plant has a nominal capacity of 6.0 m.g.d. and treats a water having the following characteristics: alkalinity, as CaCO_3 , 140 to 240 p.p.m.; soap hardness, as

CaCO_3 , 40 to 65 p.p.m.; color, 35 to 78 p.p.m.; pH, 8.2 to 8.6; temperature, 78° to 80°F. The water is obtained from wells. The ferric chloride (as anhydrous salt) dosage ranges from 0.7 to 2.8 and averages 1.7 g.p.g. The filtered effluent is brilliantly clear and has a residual color said to be about 13 p.p.m. Inasmuch as this plant will be described at this session by Mr. R. O. Van Meter, Chief Operator, no further reference to it will be here attempted.

In 1930 Potter and Klein (21) conducted experiments with the use of ferric chloride in substitution for alum for the treatment of the soft colored water of Mamaroneck River at Westchester, N. Y., Joint Water Works no. 1. The results secured were so satisfactory that ferric chloride treatment was recommended as a regular procedure. Potter and Klein reported that, when alum was used, difficulty was had with coagulation at low temperatures; good floc formation was possible only within a narrow pH range; both over- and under-dosing caused pin point floc formation of colloidal character, impossible of subsidence within the available settling period, with resulting cloudiness of filter effluent containing both color and aluminum hydroxide; if and when floc formed it was too light and buoyant to settle effectively within the retention period provided in the sedimentation basins and in consequence blanketed the filters, causing short runs; variations in draft upon the settling basins and attendant variations in water level disturbed them to such extent that heavy floc was carried over to the filters; during floods the filters were forced to carry an extreme load which still further shortened the periods between washings; the filters gave trouble from air binding and the sand grains were coated with gelatinous aluminum hydroxide films difficult if not impossible to remove; the secondary settling basins required to be put out of service and cleaned monthly despite the fact that they were provided with mechanical desludging equipment.

The results of ferric chloride coagulation are reported in the following terms: floc formed satisfactorily at all temperatures, even the lowest when the stream was frozen over, and at all pH values between 6.0 and 7.6 without any apparent detrimental or especially favorable action arising out of this condition; while under-dosing would not produce the desired results, over-dosing, except for the additional and unnecessary expense, had no deleterious effects; the floc formed was heavy and settled rapidly in the sedimentation basins; the filter runs were lengthened; variations in settling basin levels and floods

did not involve extraordinary filter loadings; the filters could be shut down without difficulty from entrained air; the accumulations of sludge in the mechanically cleaned secondary clarifiers were greatly (75 percent) reduced; the filter sand was restored to its original clean condition free of gelatinous adhesions; without filtering to waste, the effluent of the filters was brilliant at all times.

Stegeman (22) has reported upon the use of ferric chloride for the treatment of Tittabawassee River water at Midland, Michigan. Here 1 g.p.g. of ferric chloride (reported as anhydrous salt, presumably) reduced the turbidity of the water from 33 to 5 p.p.m., whereas 2 g.p.g. of alum was necessary for the same result. This water is ordinarily softened with lime. Ferric chloride has given uniformly satisfactory results with a considerable reduction in cost to date. As compared with alum there has been no apparent improvement in color removal or in length of filter runs. The ferric chloride is said to hydrolize readily regardless of the initial pH of the water. This was not the case with alum when used without lime treatment unless or until a considerable dose had been applied.

It may be noted in this connection that ferric salts, especially ferric chloride, are finding favor as conditioning chemicals in the dewatering of sludge at sewage treatment plants.

AVAILABILITY AND COST OF FeCl_3

As previously noted, during 1930 ferric chloride became available in the United States in quantity and at a cost which in some cases can compete with other coagulants, including alum. The actual cost to the consumer depends upon: (1) the form in which it is purchased, whether anhydrous (practically 100 percent FeCl_3), solid (or lump) containing 58 to 59 percent available FeCl_3 , or aqueous solution; (2) the amount purchased at any one time; and (3) the transportation distance from point of manufacture.

Recent quotations on ferric chloride, calculated as per ton both of anhydrous (100 percent) FeCl_3 and as made and shipped in California, are presented in table 3.

Ferric chloride solution is commonly quoted on the basis of anhydrous (100 percent) FeCl_3 . Solid and lump ferric chloride are quoted on the dry weight basis of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ crystals containing from 58 to 60 percent of anhydrous (100 percent) FeCl_3 .

In this connection it may be interesting to examine the calculated comparative or competitive costs of various coagulants on the basis

of the soluble or available oxides which they contain. Professor Langelier has suggested that the comparison be made by assigning various money values per "unit" of available oxide, a "unit" being taken to be 1 percent of the gross weight or 20 pounds per ton of the coagulant. With his help the writer has computed the values presented herewith in table 4. The figures have been calculated for several ferric coagulants and for standard 17 percent aluminum sulfate. Table 4, with its accompanying notes, is believed to be self-explanatory. The actual cost in dollars per "unit" of any of the

TABLE 3

Recent quotations on ferric chloride in California calculated on basis of anhydrous (100 percent) material and as actually manufactured and shipped

FORM	COST ON ANHYDROUS BASIS PER TON	ACTUAL COST AS MADE AND SHIPPED PER TON	HOW QUOTED
Solution (1000 to 8000 gal. lots)	\$60.00	\$25.80-30.00	Delivered in California
Solid cake 100 pound drums	67.80	39.30-40.70	f.o.b. mfg. plant
Solid cake 350 pound drums	61.00	35.40-36.60	f.o.b. mfg. plant
Lumps 100 pound drums	76.30	44.30-45.80	f.o.b. mfg. plant
Lumps 350 pound drums	69.50	40.30-41.70	f.o.b. mfg. plant

NOTE. The cost per ton, on anhydrous basis, of cake and lumps has been computed on the basis of a content of 59 percent available or anhydrous FeCl_3 .

The costs per ton of solution "as made" have been calculated on the assumption that the contents of available FeCl_3 are 43 and 50 percent, respectively.

The costs per ton of cake and lumps "as made" assume respective contents of 58 and 60 percent of available FeCl_3 .

In California solid cake ferric chloride is quoted 25 cents per 100 pounds lower than the lump material.

several materials included in the table, upon which a quotation may be had, may be obtained by dividing the quoted figure by the value per ton of the material in question calculated with the value of \$1.00 per "unit" as given in the table. Thus, if lump ferric chloride containing 59 percent by weight of available or anhydrous ferric chloride is quoted at \$41.00 per ton, the value per unit is 41.00 divided by \$29.10 or \$1.41. The values per ton for other costs than \$1.00 per "unit," as found in the table, are presented simply to make comparison easy by ordinary inspection methods.

All of the coagulants included in the table are complete products

TABLE 4
Relative or competitive costs of certain ferric and aluminum coagulants with certain assigned values per unit of soluble or available Fe_2O_3 or $\text{Al}_2\text{O}_3 = 20$ pounds.

NO.	COAGULANT	STRENGTH, PERCENT	UNITS OF OXIDES PER TON OF MATERIAL	VALUE PER TON OF STATED MATERIAL WITH VARIOUS ASSIGNED VALUES PER UNIT OF AVAILABLE OXIDES					
				\$1.00	\$1.50	\$2.00	\$2.50	\$3.00	
1	FeCl_3 , anhydrous	100 FeCl_3	49.2	\$49.20	\$73.90	\$98.50	\$123.10	\$147.70	
2	$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, solid or lump	59 FeCl_3	29.1	29.10	43.60	58.10	72.60	87.20	
3	FeCl_3 , solution	50 FeCl_3 45 FeCl_3 40 FeCl_3	24.6 22.2 19.7	24.60 22.20 19.70	36.90 33.20 29.60	49.20 44.30 39.40	61.60 55.40 49.20	73.90 66.50 59.10	
Scrap iron plus chlorine									
				142.90	214.40	285.80	357.30	428.80	
4	FeCl_3 , scrap iron + chlorine	100 FeCl_3	142.9 (of Fe.)	Scrap iron, only, with chlorine at (1) 3¢, (2) 4¢, (3) 5¢ per lb.					
				(1) 28.80 (2) -9.30 (3) -47.40	(1) 100.20 (2) 62.20 (3) 24.20	(1) 171.60 (2) 133.60 (3) 95.60	(1) 243.20 (2) 205.10 (3) 167.00	(1) 314.60 (2) 276.60 (3) 238.60	
5	$\text{Fe}_2(\text{SO}_4)_3$, anhydrous	100 $\text{Fe}_2(\text{SO}_4)_3$	40.0	40.00	60.00	80.00	100.00	120.00	
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ (99 percent)—copperas—plus chlorine									
				28.50	42.70	56.90	71.10	85.40	
6	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + chlorine (chlorinated copperas)	54.1 FeSO_4	28.5 (of copperas)	Copperas (99 percent), only, with chlorine at (1) 3¢, (2) 4¢, (3) 5¢ per lb.					
				(1) 20.90 (2) 18.30 (3) 15.80	(1) 35.10 (2) 32.60 (3) 30.10	(1) 49.30 (2) 46.80 (3) 44.20	(1) 63.60 (2) 61.00 (3) 58.50	(1) 77.80 (2) 75.20 (3) 72.80	
7	$\text{Al}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$	17 Al_2O_3	17.0	17.00	25.50	34.00	42.50	51.00	

ready for the usual procedure of application except no. 4, FeCl_3 solution, produced at the plant from scrap iron and chlorine, and no. 6, chlorinated copperas.

The production of ferric chloride solution from scrap iron and chlorine must be regarded as a manufacturing process requiring special equipment and scientifically controlled procedure. It is obvious that the values presented in table 4 do not, therefore, truly represent the relative or competitive costs of ferric chloride solution thus produced. To obtain such costs there must be deducted from the tabulated values the costs represented by interest, depreciation and maintenance of the manufacturing plant, together with the amount of labor and expert supervision chargeable to manufacture per se. When these costs are so deducted the apparent advantage of ferric chloride solution will disappear for all plants except those which are relatively large and, among these, only the ones where the conditions for such production are particularly favorable. Among these favorable conditions is that of long haul for manufactured coagulants ready for the usual procedures of application.

In contrast, the production of chlorinated copperas involves little additional equipment and labor properly chargeable to its manufacture. The relative or competitive values for this product as presented in the table may therefore be regarded as reflecting, for most cases, its true economic worth.

In this general connection it might be appropriate to suggest to purchasing agents and treatment plant operators that consideration be given to the desirability of obtaining from manufacturers quotations on coagulants on the unit basis: i.e. the cost per unit of soluble or available oxides.

PURCHASE, DELIVERY AND STORAGE

The form in which ferric chloride should be purchased will depend primarily upon the rate of use and secondarily upon the facilities for delivery. If large quantities are demanded and if a railroad siding is available at the treatment plant, there can be no question but that the supply should be purchased and delivered in solution form in tank cars. Where smaller yet considerable quantities are used and where delivery can be made in trailers, as is the case in the Los Angeles area, it is probable that here again the supply should be obtained in the form of aqueous solution. In all other cases, the anhydrous or the so-called solid form should be purchased, the size of the containers being determined by the rate of use and the facilities for handling

and storage. Whether the supply should be obtained in anhydrous form or in solid cake or lump form will depend upon the price quotation and, to some degree, upon the dissolving or solution equipment provided at the plant and the time available for the preparation of solutions ready for application.

Rubber-lined steel tank cars, as employed in California and elsewhere, hold some 8000 gallons. If thus delivered, the storage capacity at the plant should probably be not less than 10,000 and preferably as much as 12,000 gallons. Rubber-lined steel delivery trailers as used in the Los Angeles district have a capacity of 1,000 gallons. If thus furnished, the storage capacity at the plant, to provide for ordinary emergencies with respect to purchase and delivery, should probably be not less than 1,500 gallons. Ferric chloride solution is also furnished, in California, in 55-gallon rubber-lined steel drums and in 5-gallon stoneware jugs.

If purchased in drums or wooden casks in solid form, the storage capacity to be provided will be determined both by the rate of use and by the manner and size of shipment, whether by carload lots, partial carloads, or by truck. In eastern United States lump ferric chloride is shipped by certain manufacturers in heavy paraffin lined air tight wooden casks of 55 gallons capacity, holding about 430 pounds, net, of broken lump. It is advised that wooden containers be set in single tiers. Stored in this manner about 40 square feet of floor space are required for each ton of material. In California ferric chloride, in both solid and lump form, is shipped in two sizes of lacquered iron drums, one containing 100 pounds and the other 350 pounds. Such drums can be stored in several tiers, either on their ends or sides, thus reducing the storage space otherwise necessary with a single tier. Dimensional and other data applying to these containers are as follows:

FORM OF COAGULANT	SIZE OF PACKAGE	DIAMETER	HEIGHT	GAUGE OF METAL	FRICTION CAP DIAMETER	TARE WEIGHT
	pounds	inches	inches		inches	pounds
Lumps.....	100	14.1	21.0	28	8	6
Lumps.....	350	21.0	32.5	25	8	19
Solid cake.....	100	14.1	12.9	28	8	4.5

Each problem of purchase, delivery and storage should be carefully considered and determined on the basis of the existing and probable future conditions.

Storage of ferric chloride solution should preferably be provided in either rubber-lined steel tanks or dense-concrete tanks carefully protected by latex, or asphaltum and felt linings. These tanks may be placed in or on the ground as conditions dictate. Wooden tanks of heavy construction may be employed, but their use is not advised under ordinary circumstances because the two other types of containers are better and less likely to give trouble. If wooden tanks are used, they should be so constructed that the bands or rods which hold them together may be tightened from time to time to take up the shrinkage in the wood due to the astringent action of the ferric chloride solution. Such bands or rods should be separated from the tank by proper wooden spacers. The tanks should be lined with latex or other suitable acid resistant coating.

A good type of asphaltic lining for concrete tanks may be produced as follows:

1. Dry the tank thoroughly after the concrete has been well cured.
2. Wash the interior and top surfaces with a solution of hydrochloric acid, and rinse with water.
3. Allow to dry *thoroughly*.
4. Apply to interior and top surfaces a hot coat of asphaltic mixture made up of equal portions of Texas and Trinidad asphalts.
5. Apply a triple layer of Johns-Manville, or equal, asbestos roofing felt, 32 inches wide, and mop each layer on thoroughly with the hot asphaltic mixture above described (4).
6. Apply a second hot coat of asphaltic mixture, over the felt, as in (4).

APPLICATION OF FeCl_3

Because of its hygroscopic qualities, solid ferric chloride can not be applied to water through any of the various types of dry feed machines commonly used for stable granular chemicals. In order to apply this form of ferric chloride it must first be dissolved and then diluted to such strength as may be desirable for application.

The strength of the solution, whether purchased as such or obtained directly from the solid form, as actually applied to the water depends largely upon the rate of use and the accuracy with which dosing is to be accomplished. Other things being equal, fairly large volumes of liquid can be regulated and measured more accurately than can very small quantities. Each case must be determined upon to best meet the local conditions. In general it may be said that the strength

of solutions, as applied under different conditions, may vary from possibly 2 percent in very small plants to 20 percent or even greater in large plants well equipped with mixing and conditioning devices.

The solution of proper, predetermined strength should be regulated and measured in some form of orifice tank. The construction must be of non-corrodible substances throughout. The available materials are hard and soft rubber, stoneware, glass and wood, Haveg, and certain iron alloys as herein before mentioned. Several manufacturers can supply hard-rubber orifice boxes excellently adapted to this service. Very satisfactory "home made" devices are possible, as exemplified by the solution feeder employed at the La Cienega Filtration Plant at Beverly Hills. This device operates on the orifice (nozzle) principle and consists of a suitable fixed level tank from the bottom of which a rubber hose, terminated by a glass nozzle, leads. By setting the nozzle at different distances below the surface of the solution in the tank any desired rate of discharge may be obtained. The actual rate is indicated on a scale read opposite the tip of the glass nozzle.

The orifice feed tank should be supplied with solution of proper density or strength from what is sometimes called the "daily supply" tank. This in turn is supplied from the main storage tank if the ferric chloride is obtained in solution form.

The solution may be elevated from the main storage tank to the "daily supply" tank by means of hard rubber, rubber-lined, or iron alloy centrifugal pumps or, perhaps better, by air ejectors constructed on the old Shone sewage ejector principle. In the latter case all that is required is a rubber-lined steel barrel, so located as to be filled by gravity from the main storage tank, suitable hard rubber valve controls, the necessary piping of hard rubber or rubber hose, and a small "filling station" type of air compressor and air storage tank. An excellent installation of this type can be seen at the La Cienega Filtration Plant at Beverly Hills.

Where the solution must be prepared from the solid form of ferric chloride, consideration must be given to the proper size, design and construction of the dissolving equipment.

If the material is received in steel drums the simplest construction would involve latex or asphaltum lined concrete tanks in which the drums, previously punctured with holes, using a pickax, are set upon blocks to raise them slightly above the bottom. Water should be introduced to completely submerge the drums.

The time required to dissolve the lump ferric chloride in drums,

treated as above described, is surprisingly short. By actual experiment a 100 pound drum of this material was dissolved in 70 gallons of water in 30 minutes. The cover of the drum had been removed and the sides had been punctured with holes. If a corresponding volume of water is used it is believed that the contents of a 350 pound drum would dissolve in about the same length of time. In comparison with the lump material it is probable that the solid cake would require from two to three times as long to completely dissolve.

If the material is received in wooden casks, it may perhaps best be dissolved upon suitable wooden racks built into the top of concrete solution tanks. The water in the tank may be heated if it is desired to accelerate the solution process.

Messrs. Innis, Speiden and Company, New York City, have prepared a bulletin (7) on ferric chloride, its characteristics and proper manner of handling. This should be consulted for further details concerning the design of dissolving tanks and the preparation of ferric chloride solutions.

The strength of a ferric chloride solution can be determined very quickly and simply and with fair accuracy by the use of a high grade hydrometer employing either the specific gravity or the Baumé scale. In making an hydrometer determination accuracy demands that the temperature of the solution be observed and that such correction therefor as may be necessary be applied to the hydrometer reading. See tables 1 and 2.

The proper dosage of any coagulant, and this observation applies to ferric chloride as well as others, should be accurately determined for any set of conditions by the use of laboratory stirring apparatus of which various forms are now being produced commercially and can be furnished by chemical supply houses. A stirring mechanism of this sort was devised by Langelier (8) as early as 1919 and was used to determine the optimum treatment (with alum) of Sacramento River water at Sacramento. The results of the laboratory findings should be carefully checked by actual plant accomplishments (23) in order to establish as definitely as possible a basis for the predetermination of plant performance from laboratory observations.

COAGULATION CONTROL AND MIXING OF COAGULANT

The best practice prescribes that the coagulant dosing shall be closely regulated to the condition of the water undergoing treatment, as just indicated, and to the volume of flow. Frequent samples should

be taken to insure that optimum coagulation is being effected and this with a minimum amount of chemical. It is desirable that the laboratory tests shall be made with the coagulant actually being employed in the plant and taken from the dosing device itself. In some cases it may be necessary to adjust the pH value to conform to the requirements of satisfactory floc formation. In certain cases, also, post-coagulation adjustment of the hydrogen ion concentration, on the alkaline side, may be necessary in order to neutralize the corrosivity of the treated water and prevent pipe attack and consequent red water troubles. Each problem must be worked out with reference to the local controlling conditions.

The coagulant solution should be rapidly and completely mixed with the water to which it is applied so that it will be uniformly dispersed throughout the mass. This may be done by introducing the coagulant in advance of pumping, where the water is lifted by pumps directly into the floc conditioning devices, by air agitation in properly designed tanks, by the hydraulic jump, or by rapid stirring in the first of a series of floc conditioning tanks.

CONDITIONING OF THE FLOC

To obtain the maximum efficiency from any coagulant it must be properly coagulated and the largest possible mass of floc formed in the mixing chamber. The individual floc particles should be large and firm, that is, not unduly fragile. The procedure of building up large, stable floc masses has become known as floc conditioning. It implies turbulent, preferably rotary, motion in the conditioning channels or chambers, whereby the floc particles are brought into constant contact, or collision, or gentle bombardment, if there be such a thing, one with another until the maximum possible degree of coalescence is brought about. A well conditioned floc will settle rapidly and will withstand a certain amount of shock in transportation in conduits. Even well conditioned floc should not, however, be subjected to sudden changes in direction at high velocities, or to jet flow, or to flow over weirs or other similar barriers.

Floc conditioning may be successfully effected by turbulent (in the hydraulic sense) flow in long unbaffled channels, in channels with under- and over-baffles, in channels with around-the-end baffles, in circular or multi-sided tanks provided with rotating vertical axle paddles, or in rectangular basins provided with horizontal axle paddles; and in basins provided with compressed air agitation alone

or combined with mechanical stirring. In any case the velocity of travel should range from about 0.5 to 1.5 foot per second, or perhaps slightly higher. The period required for flock conditioning varies with different waters, temperatures, perhaps with the coagulating chemical employed, and possibly with the type of conditioning equipment. In general the period provided, after proper mixing, should be not less than 20 and preferably 30 minutes. It is probably rarely that a greater length of time need be provided for the average rate of yield of a plant.

Nolte and Kramer (24) conducted a comprehensive series of investigations, employing sulphate of alumina as a coagulant, on the velocity and time of floc conditioning. Their conclusions maybe stated in part as follows:

(1) Good results can be obtained with velocities ranging from 0.5 to 1.5 foot per second through a period of 30 minutes, provided that the dosage of coagulant is sufficient.

(2) Velocities greater than 1.5 foot per second for any time period from 1 to 60 minutes give poor results.

(3) Mixing in water at a high velocity followed by conditioning at 1.0 foot per second give results comparable with uniform velocities of any value between 0.5 and 1.5 foot per second for the same period of time.

(4) The higher the charge of coagulant (in their case, aluminum sulfate) the more rapidly is the floc formed; lower charges will require longer periods of conditioning; but a deficiency in dosage cannot be compensated for by prolonged periods of conditioning.

Willcomb (14) states that proper conditioning will effect large savings in the amount of coagulant required. He cites the experience of Hoover, at Columbus, who demonstrated that 4.0 g.p.g. of alum with quick mixing and subsequent low velocities gave results equivalent to those secured with from 6.0 to 8.0 g.p.g. with improper and inadequate conditioning. At Reading, Pennsylvania, Cox found that 20 minutes at 0.25 foot per second gave the same results as 8 minutes at 0.8 foot per second. At Sacramento, California, Langelier determined that doses of alum ranging from 0.5 to 0.8 g.p.g., velocities of from 0.2 to 2.0 feet per second, and retention periods of from 10 to 20 minutes would condition water containing 200 p.p.m. of turbidity in a manner or to a degree completely satisfactory for subsequent clarification. In water softening practice Willcomb states that from 87 to 90 percent of the reaction is effected by proper conditioning. He concludes that conditioning for 20 to 30 minutes at velocities of from 0.5 to 1.0 foot per second will give good results under ordinary conditions.

Based upon his extensive experience with the treatment of clear, sewage contaminated waters, Willcomb (14) concludes that such waters require large coagulant (alum) doses and careful (optimum) conditioning. The reaction pH value during the initial mixing varies with the oxygen consumed value of the water. As the organic content increases the pH value at which optimum coagulation occurs decreases in like proportion. This type of water does not seem to require violent agitation. If clarification basins providing a 2-hour retention period are assumed, conditioning velocities of 0.8 foot per second for 10 minutes or 0.4 foot per second for 14 minutes are required.

Some waters respond better to violent agitation at the beginning followed by a decreasing conditioning velocity. There is some evidence that certain types of colored waters require more prolonged conditioning than do common types of turbid waters. It is particularly important that the comparatively delicate "color floc" formed at low pH values be not broken up in transportation through conduits and apertures.

The mixing and conditioning arrangements at the Wilmington plant of the Los Angeles Department of Water and Power, described at this meeting by Mr. R. O. Van Meter, constitute an excellent example of good design adapted to the use of ferric chloride as a coagulant applied for purposes of color removal.

SEDIMENTATION WITH FeCl_3 AS A COAGULANT

There is abundant evidence that ferric floc is relatively heavy and that when properly formed and conditioned it settles rapidly. If sedimentation basins are properly proportioned, are well designed with respect to such details as inlet and outlet arrangements, baffles and the like, and provide an adequate effective retention period, there should be no reason to expect other than satisfactory results.

It is believed to be beyond the immediate scope of this paper to discuss the fundamental principles of sedimentation of coagulated waters or the features of design of settling basins. Excellent discussions of these matters are to be found in the literature, both in recently published text and reference books dealing with water purification and sewage treatment and in the technical journals. Among recent discussions of the subject may be mentioned A. B. Morrill's paper on Sedimentation Basin Research and Design (25) and G. J. Schroeffer's paper entitled "Factors Affecting the Efficiency

of Sewage Sedimentation" (26). The writer has discussed briefly the matter of prevention of shortcircuiting and the application and design of diffusion baffles as related thereto (27). The performance of experimental baffles in the coagulating and sedimentation basin at Montebello Filters, Baltimore, has been discussed by J. W. Armstrong (28) (29).

METHODS OF ANALYSIS OF FeCl_3

Because of the fact that ferric chloride has so recently come into the water and sewage works field, the procedure of analysis of this material has not, it is believed, become a matter of general knowledge among chemists operating such plants. For that reason it may be of value to extend the scope of this paper to include a method recommended by Dr. W. Hirschkind, Technical Director, Great Western Electro-Chemical Company, and used by his staff in the control of the manufacturing process. The procedure is as follows:

Method of analysis of ferric chloride

Solutions:

$\text{N}/10 \text{ KMnO}_4$:

Dissolve 31.60 grams of C.P. KMnO_4 crystals in 10 liters of distilled water. Allow it to stand at least one month, then decant into another bottle, discarding any sediment. Standardize as follows: dissolve approximately 0.3 gram of sodium oxylate (Bureau of Standards) in 200 to 250 cc. of 1:1 sulphuric acid and titrate at once with the KMnO_4 solution, stirring the liquid vigorously. The KMnO_4 must not be added more rapidly than 10 to 15 drops per minute and each drop must be allowed to decolorize before the next is added. The temperature should be above 60°C . at the finish.

Stannous chloride:

Dissolve 80 grams of C.P. SnCl_2 in 500 cc. of C.P. concentrated HCl and 500 cc. distilled water. Place a small piece of metallic tin in the solution.

Mercuric chloride:

Make up a saturated solution which will contain approximately 70 grams per liter.

Titrating mixture:

Dissolve 160 grams of manganous sulfate C.P. in distilled water and dilute to 1750 cc. Add 330 cc. of C.P. phosphoric acid (85 percent) and then stir in 320 cc. of C.P. sulphuric acid (specific gravity 1.84).

Procedure:

Make the determination on the clear liquor taking care that any oxychloride sludge is allowed to settle before taking the sample, otherwise high results will be obtained. Bring the ferric chloride liquor to a temperature of 20°C . and accurately weigh 10 cc. in a pycnometer (by referring to the weight of 10 cc. of water at the temperature, this will give the specific

gravity as well as the known weight of the sample). Carefully wash the sample from the pycnometer into a 500 cc. volumetric flask and dilute to the mark at 20°C. Pipette a 25 cc. sample into a 600 cc. beaker. Add 15 cc. of concentrated C.P. HCl and bring to boiling. While boiling add stannous chloride solution drop by drop until the iron is completely reduced, then add two drops excess. The point of complete reduction is shown by the water-white character of the solution; or a test may be made for ferric iron by removing a drop on a spot plate and mixing with a drop of KCNS solution. Cool to room temperature, dilute to approximately 100 cc. Add 25 cc. mercuric chloride all at once and stir vigorously. Then add 30 cc. of the titrating mixture and dilute to the full capacity of the beaker with distilled water. Titrate with $N/10$ $KMnO_4$ until a pink color permanent for 30 seconds is obtained.

Ferrous chloride:

To determine the ferrous chloride, proceed as for the ferric chloride, but with no addition of stannous chloride.

Blank:

Run a blank on the $KMnO_4$ by using all of the above solution in the same manner as in an actual determination. The blank will usually require about 0.1 cc. $KMnO_4$.

Calculations:

$$\frac{(\text{cc. } KMnO_4 - \text{blank} - \text{cc. } KMnO_4 \text{ for ferrous}) \times 0.3244}{\text{Weight of sample}} = \text{percent } FeCl_3$$

$$\frac{(\text{cc. } KMnO_4 - \text{blank}) \times 0.2535}{\text{Weight of sample}} = FeCl_2$$

Note: In analyzing solid ferric chloride, weigh approximately 10 grams of the material accurately in a weighing bottle, wash into a 500 cc. volumetric flask and proceed in the same manner as when analyzing the liquor.

A somewhat more comprehensive outline of analytical methods, to determine insoluble matter, total soluble iron as Fe, ferric iron as Fe, and ferrous iron as Fe, is to be found in Innis, Speiden and Company's booklet on ferric chloride (7).

A Committee on "Methods of Analysis of Water Purification Chemicals" was appointed by Chairman Ellms of the Water Purification Division of this Association following the annual convention in Memphis in 1932. A progress report was given at the Chicago convention, June 13, 1933, where it was stated that 18 or 19 monographs, each on a different chemical, had been prepared and were to be reviewed prior to publication. The final report of this committee in the form of the approved monographs has not yet been issued. When it is published it should constitute a valuable contribution to this field (30).

PROTECTION AGAINST ACCIDENTS

Ferric chloride is irritating to the skin and particularly so to the eyes. Every precaution should be taken to prevent splashing of ferric chloride solutions into the eyes. Bicarbonate of soda and zinc peroxide ointment should be kept on hand in an accessible place at all times.

TREATMENT FOR FERRIC CHLORIDE BURNS

Flesh burns. Remove any ferric chloride by thorough washing with water followed by the application of a neutralizing solution of bicarbonate of soda. This treatment should be followed by an application of a salve, preferably zinc peroxide ointment.

Eye burns. If ferric chloride gets into the eye irrigate immediately with copious amounts of clean water, followed by an application of 2 percent solution of sodium bicarbonate. If serious, the injury should be treated by a physician as promptly as possible.

FeCl₃ TEST SOLUTIONS

Add 4.28 grams of ferric chloride to distilled water to make up 1000 cc. Four cubic centimeters of this solution added to 996 cc. of water will produce a solution having a strength of 1 grain per gallon of the kind of ferric chloride salt employed. To convert this strength to equivalent strength of anhydrous or 100 percent FeCl₃, multiply by the percentage strength of the salt actually employed.

If it is desired to make up a solution containing 1 grain per gallon of anhydrous FeCl₃ employing a salt of known percentage strength, divide 4.28 grams by the percentage strength of the salt used and proceed as above. Thus, if a salt containing 59 percent FeCl₃ is employed, it will be necessary to add 7.25 grams to make 1000 cc. of which 4 cc., diluted to 1000 cc., will represent 1 grain per gallon of anhydrous FeCl₃.

ACKNOWLEDGMENT

The writer is indebted for many helpful suggestions and data to Professor W. F. Langelier of the University of California at Berkeley, to Dr. W. Hirschkind, Technical Director, Great Western Electro-Chemical Company, San Francisco, to Mr. Ralph A. Stevenson of Los Angeles, formerly Research Engineer, Great Western Electro-Chemical Company; and to Mr. Linn H. Enslow, Editor, Water Works and Sewerage, New York, N. Y.

REFERENCES

1. Chemistry, Ira Remsen—Henry Holt & Co., New York (1899).
2. Engineering Record, 39, p. 595, 1899. Engineering News, 43, p. 351, 1900.
3. Manual of American Steel and Wire Company's System of Water Purification, Chicago, 152 pp., 1916.
4. George C. Whipple—Proc. 26th. Meeting, Amer. W. W. Assoc., 1906.
5. Proc. Illinois Water Supply Assoc., 3, p. 66, 1911. Municipal Engineering, Vol. 42, p. 159, 1911.
6. Engineering News-Record, 100, p. 147, 1928.
7. Handy Information on Isco Ferrie Chloride—Innis, Speiden and Co., 117-119 Liberty Street, New York City; also, Industrial Chemicals—Great Western Electro-Chemical Co., 9 Main Street, San Francisco, Cal.
8. Engineering News-Record, 86: 22, June 2, 1921, pp. 924-928.
- 8a. Indian Jour. Medical Research, 1916.
- 8b. Chem. and Metallurgical Eng., 24: 17, April 27, 1921, pp. 728-735.
9. Public Health Reports, 40: 27, July 3, 1925, pp. 1415-1416.
10. Proceedings A. S. C. E., 59: 10, December 1933, pp. 1529-1542.
11. Jour., New England W. W. Assoc., 47: 3, September, 1933, pp. 273-279.
12. Jour. Amer. W. W. Assoc., 24: 5, May 1932, p. 733.
13. Public Health Reports, 40: 28, July 10, 1925, pp. 1472-1481.
14. Jour. Amer. W. W. Assoc., 24: 9, September 1932, p. 1419 et seq.
15. Water Works and Sewerage, 79, p. 301, 1932.
16. Public Health Reports, 40: 27, July 1925, pp. 1417-1418.
17. Jour. Amer. W. W. Assoc. 20: 4, October 1928, pp. 467-472.
18. Medeeelingen Van Den Dienst Der Volksgezondheid in Nederlandsch-Indie, 19, Part I, pp. 23-29, 1930.
19. Ind. and Eng. Chemistry, 25: 10, October 1933, pp. 1110-1112.
20. Western Construction News, 7: 6, March 25, 1932, pp. 167-168.
21. Jour. Amer. W. W. Assoc., 23: 5, May 1931, pp. 725-727.
22. Water Works Engineering, 85: 22, November 2, 1932, pp. 1318-1320.
23. Hopkins, Water Purification Control—Chap. I, Williams & Wilkins Co., Baltimore, 1932.
24. Jour. Amer. W. W. Assoc., 25: 9, September 1933, pp. 1263-1278.
25. Jour. Amer. W. W. Assoc., 24: 9, September 1932, p. 1442 et seq.
26. Sewage Works Journal, 5: 2, March 1933, pp. 209-232.
27. Western Construction News, 8: 16, October 1933, p. 413.
28. Jour. Amer. W. W. Assoc., 6: 2, June 1919, pp. 160-166.
29. Jour. Amer. W. W. Assoc., 7: 4, July 1920, pp. 456-460.
30. Jour. Amer. W. W. Assoc., 26: 4, April 1934, pp. 532-537.

DISCUSSION

W. F. LANGEIER (*Berkeley, Calif.*):

In the relative evaluation of ferrie and alum coagulants for service where either is adapted, the statement is frequently made that one ton of anhydrous ferrie chloride is equal in coagulating capacity to

2.5 tons of standard aluminum sulphate containing 17 percent available Al_2O_3 . This is based on the fact that one pound of FeCl_3 will yield by hydrolysis 0.663 pound of $\text{Fe}(\text{OH})_3$, whereas the same weight of alum will yield 0.26 pound of $\text{Al}(\text{OH})_3$ or $\frac{0.663}{0.26} = 2.5$.

In the absence of experimental data, this assumption is not altogether justified. In fact, it would seem that it would be equally logical to assume that the two hydroxides possess equal coagulating value, molecule for molecule rather than pound for pound. On a molecular basis one pound of FeCl_3 would be equivalent to $\frac{1.0}{0.54}$ or 1.85 pound of alum. The difference is appreciable, and with this thought in mind a few simple experiments were made to estimate the relative bulk of the two hydroxides produced from equimolal solutions of the two coagulants. The two solutions contained respectively 0.54 gm. of anhydrous FeCl_3 and 1.0 gm. of standard alum per liter. Fifty cubic centimeter portions of these solutions each mixed with 50 cc. of 0.02 molal NaHCO_3 solution yielded, after standing 24 hours in a graduated centrifuge tube, respectively 2.0 cc. of $\text{Fe}(\text{OH})_3$ and 3.0 cc. of $\text{Al}(\text{OH})_3$. Centrifuging reduced the volumes to 0.5 and 0.8 cc. respectively. This experiment was repeated several times and gave similar results. Thus, if relative coagulating efficiency is measured in terms of bulk of settled precipitate, it would appear from this experiment that one pound of FeCl_3 is equivalent to $\left(\frac{1.00}{0.54} \times \frac{2}{3}\right) = 1.23$ pounds of standard alum.

Several series of the usual jar tests with turbid water were made using equimolal dosages of both coagulants, and in all cases the volume of the settled alum floc was at least equal to the volume of ferric floc. Whether or not, however, clarification efficiency is more nearly related to weight of precipitate, or volume of floc, was not determined.

It should be mentioned that in the jar tests just reported, dosages slightly larger than critical were used and that the ferric coagulant usually produced much larger flocs but fewer in number.

Present practice seems to indicate that ferric coagulants are to be preferred in sewage works where the predominating colloids are of the emulsoid type and alum the best choice for water purification works where the predominating colloids are of the suspensoid type.

In certain cases it would seem that mixtures of the two coagulants might be used to advantage.

In regard to relative costs per ton, although ferric coagulants are made from reclaimed or by-product raw materials (scrap iron and by-product chlorine from the manufacture of caustic soda), standard alum can be produced more cheaply. Using prevailing prices of raw materials, alum can be manufactured for about \$14 per ton, whereas with scrap iron at \$6 per ton and chlorine at 3 cents per pound, the raw materials for a ton of ferric chloride would cost \$41.00.

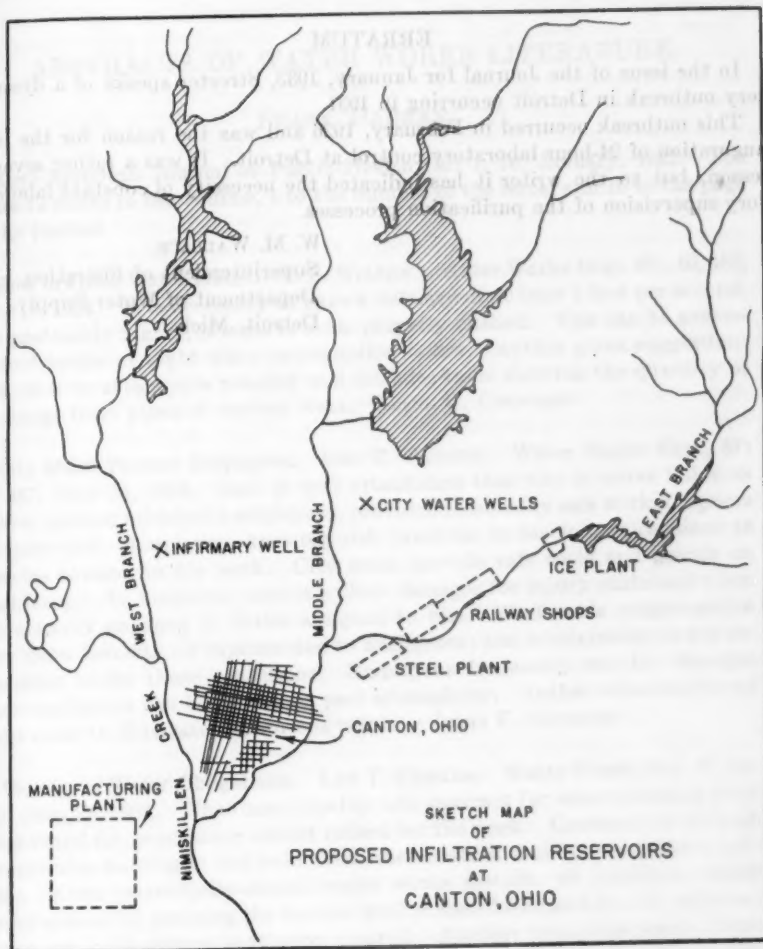
(Presented before the Water Purification Division, California Section meeting, October 25, 1934.)

A REQUEST FOR INFORMATION ON GROUND WATER REPLENISHMENT

A hearing held on February 14 at Canton, Ohio, by David C. Warner, Executive Secretary of the State Water Conservation Board, reveals an interesting case of depletion of ground water in the humid area.

All water used in the city is pumped, the source being a deep, water-bearing gravel deposit which extends from southwest to northeast. The slope is in the latter direction; southwest of the city the rock floor is at a depth of 50 feet; northeast at a depth of 250 feet. A large manufacturing plant southwest of the city procures an adequate supply—10,000,000 gallons daily—but the water table at that point has been lowered from an original depth of 8 to a depth of 30 feet. Manufacturing plants to the east of the city also procure an adequate supply. But to the northeast and north of the city the municipal water plant and a public institution are now unable to procure the necessary water—the table there has been lowered from an original depth of 14 to 100 feet. It is proposed to impound waters of the west, middle and east branches of the Nimiskillen Creek as infiltration reservoirs to replenish the ground water supply to the north and northeast of the city; and to impound for infiltration the 10,000,000 gallons discharged by the plant to the southwest of the city. Underlying gravel would be uncovered to promote rapid infiltration.

It is realized how critical is the problem of diminished ground water in the arid and semi-arid regions, but little is known of such problems in the humid eastern half of the United States. The Water Resources Section of the National Resources Board, Room 1105, Interior Building, Washington, D. C., would appreciate the receipt of information from all managers of municipal or industrial plants where significant lowering of the water table is indicated by their records.



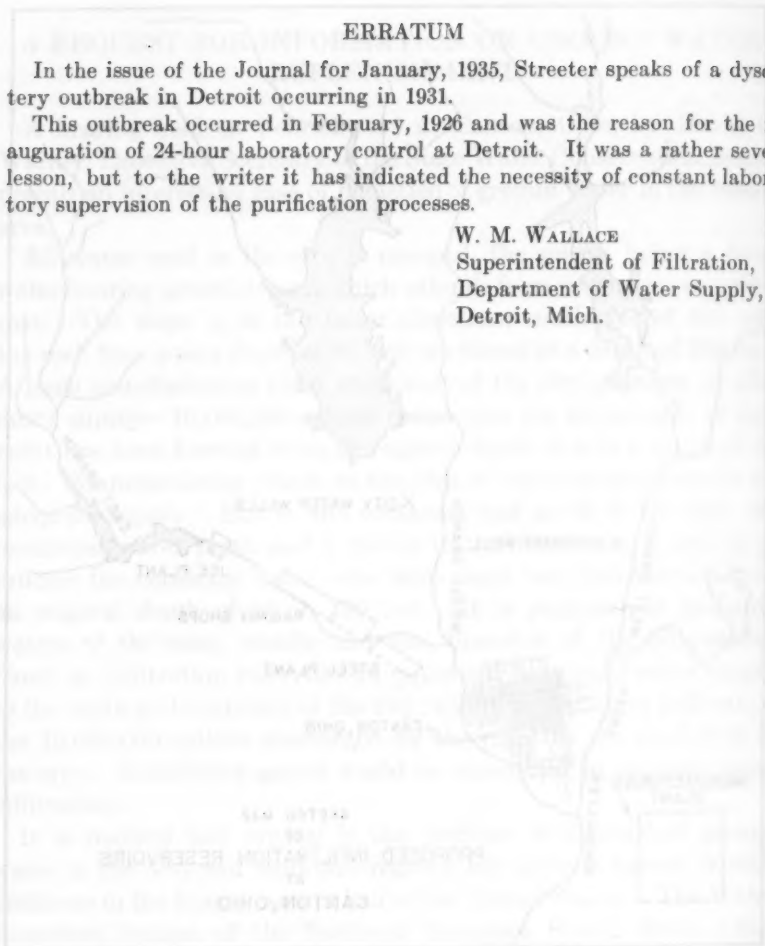
ERRATUM

In the issue of the Journal for January, 1935, Streeter speaks of a dysentery outbreak in Detroit occurring in 1931.

This outbreak occurred in February, 1926 and was the reason for the inauguration of 24-hour laboratory control at Detroit. It was a rather severe lesson, but to the writer it has indicated the necessity of constant laboratory supervision of the purification processes.

W. M. WALLACE

Superintendent of Filtration,
Department of Water Supply,
Detroit, Mich.



ABSTRACTS OF WATER WORKS LITERATURE

FRANK HANNAN

Key: American Journal of Public Health, 12: 1, 16, January, 1922. The figure 12 refers to the volume, 1 to the number of the issue, and 16 to the page of the journal.

How to Flush Water Mains. P. S. WILSON. Water Works Eng., 87: 10, 462, May 16, 1934. It is necessary to have a velocity of at least 5 feet per second, and preferably higher, if main is to be properly flushed. This can be accomplished better at night when consumption is low. Author gives suggestions as to how to attain this velocity and includes table showing the quantity of discharge from pipes of various sizes.—*Lewis V. Carpenter.*

City Must Protect Employees. LEO T. PARKER. Water Works Eng., 87: 10, 467, May 16, 1934. Fact is well established that city is never liable as insurer against injuries to employees, provided reasonably safe working spaces are provided. Employee, knowing risk involved in his job, is required to exercise caution in his work. City must provide safe tools and guards on machinery. An employee cannot collect damages for injury sustained when not actually engaged in duties assigned to him. Workmen's compensation laws allow benefits for injuries due to negligence; but municipality is not responsible under those conditions. Employees frequently sue for damages when negligence can be proved on part of employer. Author cites number of court cases to illustrate the various points.—*Lewis V. Carpenter.*

Validity of Water Obligations. LEO T. PARKER. Water Works Eng. 87-13-715, June 27, 1934. When municipality lets contract for sum exceeding bond issue voted for, contractor cannot collect for the work. Contract let without competitive bidding is not void even when statutes require competitive bidding. When municipally-owned water works installs, or improves, water works system by pledging the income until it shall have paid for the improvements, no indebtedness is thereby created. Another important point of law is that a stockholder who objects to any transaction made by water corporation officials, is bound to enter his complaint promptly; otherwise court will hold that delay has been fatal.—*Lewis V. Carpenter.*

Pipe Line Moved by Ice Floe. CHAS. F. END. Water Works Eng., 87: 13, 708, June 27, 1934. Raritan Township, N. J., during winter of 1933, had 43 joints of cast iron pipe freeze due to thawing. All of this pipe was laid across a marsh and was supported on a cross-tie crib. After this damage had been repaired, flood waters carrying heavy ice floes broke the line. One broken

length snapped off at the bell. Four thousand lineal feet of pipe was displaced, but was pulled back into place without damage.—*Lewis V. Carpenter.*

Approximate Determination of Sulfate in Drinking Water. L. W. WINKLER. Pharm. Zentralhalle, 74: 21, 319, May 1933. Accuracy of method reported by the author in 1920 for approximate determination of sulfate in drinking water can be increased by adjustment of acid concentration. To a 10-cc. sample are added 2.5 cc. of 10 per cent hydrochloric acid and then, all at once, 5 cc. of 10 percent barium chloride solution. Time until appearance of turbidity is noted with stop-watch. If this occurs in less than 5, or more than 15, seconds, determination is repeated with 5 cc. or 1 cc. of acid, and value read from a table. Method is accurate to ± 10 percent with sulfate contents of from 10 to 100 p.p.m. and is thus suited for hygienic examination, or as a field method in limnological investigations.—*Manz. Translated by Selma Gottlieb.*

The Significance of Ammonia for the Chlorine Binding Power of Water. II. M. L. KOSCHKIN. Ztschrft. f. Hyg. u. Infektionsk., 115: 1, 99, April, 1933. Ammonia added before chlorination decreases chlorine binding power of water and increases bactericidal action of chlorine. Simultaneous, or subsequent, addition of ammonia gives no such decrease of chlorine binding power and gives less increase in bactericidal activity. Sufficient chlorine to satisfy the chlorine demand after pre-ammoniation sterilized the water after three hours' contact. The content of available chlorine and the bactericidal activity of an aqueous mixture of ammonia and chlorine decrease with storage. Author considers it doubtful whether increase in bactericidal properties of chlorine by pre-ammoniation can be explained by formation of chloramines. In phenol-containing water, preammoniation decreases chlorine demand to 1 percent of its original value. Prevention of medicinal odor and taste is connected with decrease in chlorine binding power. Later addition of ammonia does not have this action.—*Manz. Translated by Selma Gottlieb.*

Changes in Bacteria after Long Storage in Water. GERHARD WERNER. Ztschrft. f. Hyg. u. Infektionsk., 115: 1, 14, April, 1933. Eighty-three strains of dysentery, typhoid, paratyphoid, and colon bacilli showed, after prolonged storage in water, only those changes characteristic of old cultures or other adverse conditions, but more extensive, more distinct, and more permanent. The changes affect morphology and mobility, form of colonies, dryness, slime formation and degeneration, sector and button formation, agglutinating power and fermentation of milk. Occurrence of lance-like forms of bacilli was especially noticeable.—*Manz. Translated by Selma Gottlieb.*

Use of α - α' -Dipyridyl for Determination of Ferrous and Total Iron in Natural Waters. HANS MÜLLER. Mikrochemie, New Series, 6: 3, 307, 1933. Color reaction of FEIGL and co-workers for determination of small amounts of iron with α - α' -dipyridyl is made applicable for limnological field investigations. Eight cc. of sample are added to 2 cc. of 1 percent solution of α - α' -dipyridyl in tube having a ground glass stopper. The solution is mixed and, after 5 minutes, resulting red color is compared with standards, column of liquid being

of same height in all tubes. For determination of total iron, 0.6 gm. of sodium sulfite is added to sample and procedure carried out as before. This reduction method can be used in presence of organic matter, which renders usual oxidation methods unreliable until after evaporation to dryness.—*Manz. Translated by Selma Gottlieb.*

Prevention of Accidents in Operation of Sulfur Baths. R. GRASSBERGER and A. LUSZCZAK. *Abh. a. d. Gesamtgebiet d. Hyg., Heft 11: 1932.* Official investigation showed that deaths of two men while working in 1300-gallon distribution tank in a sulfur bath was due to the high hydrogen sulfide content of the sulfur spring used, which had risen from 55.5 to 73.5 p.p.m. with accompanying rise in temperature from 23.9° to 28.1°C. Reconstruction of the accident indicated that when water left at bottom of tank was agitated by movements of the men at work, hydrogen sulfide content of the air increased to between 0.5 and 0.6 percent, which was rapidly fatal. Measures recommended for prevention of accidents in sulfur baths include medical supervision of hydrogen sulfide content of air in waiting rooms, baths, and tanks, avoidance of any agitation tending to increase evolution of gas, sufficient ventilation of baths and waiting rooms, administration of the baths only under medical regulation, and most careful technical supervision of installations. Water tanks must be completely emptied before workmen, who are to be provided with gas masks, are permitted to enter and must be rinsed with fresh water. Hydrogen-sulfide-free water must therefore be available in all rooms for cleaning, etc.—*Manz. Translated by Selma Gottlieb.*

Railroad Water Supply. M. SCHULZ. *Ges.-Ing., 56: 29, 343, 1933.* Railroad water station demand is determined chiefly by boiler feed water requirements for locomotives. Directions are given for calculation of feed water requirements. Quality of feed water must be same as for stationary boilers. Iron must be removed, since it will cause difficulties from accumulation in pipes, cranes, and hydrants. In laying out distribution system, easy accessibility of pipes must be considered. Under tracks, steel pipe is preferable, on account of heavy vibration.—*Manz. Translated by Selma Gottlieb.*

The Bleiloch Dam near Saalburg in Thuringia. H. HAMMERSTÄEDT. *Ztschrft. d. Ver. Deutsch. Ing., 77: 27, 739, 1933.* This reservoir, in valley of the upper Saale, has catchment area of 475 square miles, annual inflow of 108 billion gallons, and capacity of 57 billion gallons. For protection against flood, margin of 4.5 billion gallons must be allowed in winter, and of 2.5 billion gallons in April; while from June on, reservoir must be kept full, to supplement flow in the Elbe. Dam is concrete, gravity type structure, 6680 feet long and 22.5 feet wide at crest, which is 198 feet above stream bed. Total cost was 42 million Reichsmarks.—*Manz. Translated by Selma Gottlieb.*

Physical, Chemical, and Hygienic Considerations in the Use of Copper in Water Works Construction. L. W. HAASE and O. ULSAMER. *Kleine Mitteilungen d. Ver. f. Wasser-, Boden- und Luft Hygiene, 8: May, 1933, 42 pp.* In almost all waters, protective coating, consisting chiefly of cuprous oxide, forms

on copper. Time required for its formation depends upon hardness of water and its content of neutral salts and gases. In waters of high acidity (pH below 4.0) and high gas content, years may be required before protection results and in these cases copper pipes are not to be recommended; but, without preliminary treatment, such waters will usually be rejected. In normal soft surface and ground waters, without aggressive carbon dioxide and with sufficient oxygen, formation of protective coating takes at most a year; in moderately hard and hard waters, it occurs in course of weeks; during this time, copper content of water will depend on its chemical composition, and will be smaller, the harder the water. After layer has formed, copper content of flowing hot or cold water will seldom exceed 0.1 to 0.3 p.p.m. Copper normally present in human food does not cause chronic copper poisoning, and after formation of protective layer, copper intake is only very slightly increased by use of copper water pipes. It cannot be contended that this very small amount of copper would occasion bad tastes, or chronic copper poisoning.—*Manz. Translated by Selma Gottlieb.*

The Determination of Very Small Amounts of Phenol in Aqueous Solution. S. HILERT and R. GILLE. *Angew. Chem.*, **46**: 22, 326, June, 1933. Conditions were investigated for the determination of small amounts of phenol in sewage by the VON HINDEN reaction with diazotized *para*-nitraniline. Solution of diazo compound should be of about same concentration as that of phenol being determined. The dilute solution keeps about a day, with less formation of colored by-products. With *para*-nitrophenyldiazonium chloride, rapid coupling results at pH 5 to pH 8. In alkaline solution, coupling is retarded; in sodium carbonate solution at pH 11, it is complete only after 24 hours. Coupling power is also retarded by a short period of alkaline reaction. The sodium carbonate solution must therefore be added slowly dropwise, shaking to prevent local increases in hydroxyl ion concentration. After complete coupling, solution must be made alkaline immediately, since in pH zone favorable for coupling, rapid decomposition of excess diazo compound occurs. Color comparison is made in strongly alkaline solution. Thymol and alpha-naphthol can best be coupled with diazotized *para*-nitraniline; phenol, *ortho*- and *meta*-cresol, beta-naphthol, and resorcinol with diazotized sulfanilic acid. According to the original directions, mono-hydroxy-phenols and crude phenols from coke oven wastes in quantities from 0.05 to 0.1 p.p.m. can be determined directly without concentration. Sulfite wastes up to a dilution of 1:25,000 give colored compounds on azo-coupling: for this reason their presence in dilutions up to 1:50,000 interferes with the determination of phenols in surface waters.—*Manz. Translated by Selma Gottlieb.*

The Process of Fluid Mixing in Boiler Feed and Feed Water Treatment. MARCARD and BOCK. *Die Wärme*, **56**: 19, 302, May, 1933. In liquids at rest mixing occurs only through diffusion, aided occasionally by heat conduction, and takes place very slowly. In two liquid streams flowing side by side without turbulence a certain amount of exchange can result from friction, but this is usually incomplete. In turbulent flow, transverse and vortex motions cause accelerated mixing, but even here a rather long mixing path is necessary. In

usual introduction of feed water into boiler with feed trough, time available is not sufficient for complete mixing, as practical tests show. Mixing scarcely takes place when cold water is directly introduced into hot, the denser cold water sinking rapidly to the bottom. Since the water fed has in general neither sufficient time, nor height of fall, the boiler plates are chilled, strains exceeding the elasticity occur, and cracks form which are detectable from the inside. Bending of under-drum of water tube boilers during operation is also due to cold feed water. In feed water treatment, method of introducing chemicals has decided effect on mixing. With improper construction, complete utilization of reaction space is hindered by insufficient mixing. As remedy, use of artificial means for hastening mixing is recommended.—*Mans.* Translated by Selma Gottlieb.

Significance of Substances Occurring in Drinking and Industrial Waters. HARTWIG KLUT. Arch. d. Phar. und Ber. d. deutsch. pharm. Gesell., 270: 9, 554, December, 1932. To judge correctly of a water, one must have accurate information on surroundings of source, structure of underground strata, and local conditions. Drinking water installations must afford permanent protection from contamination by human, animal, or industrial wastes. Drinking water should cause no damage to health, should contain no pathogenic organisms, or poisons, should be palatable and of as uniform temperature as possible (8° to $12^{\circ}\text{C}.$). Water for use in bottling industry should keep during long storage without formation of turbidity or precipitate. Other criteria are given for evaluation of various substances. Ammonia compounds found in waters containing iron and manganese, in peat, or rain, waters, or resulting from leaching of artificial manure are of no sanitary significance. Latest standards of Prussian Health Council consider as objectionable 0.3 p.p.m. of lead in water which has stood in a lead pipe for 24 hours. In water for domestic use, 0.2 p.p.m. of iron interferes and for many industrial uses, more than 0.05 p.p.m. is undesirable. Under certain circumstances, more than 0.1 p.p.m. of iron can cause a gradual accumulation of sludge in mains. Aside from hard, chloride-containing waters, which may irritate sensitive skins in washing, there is no hygienic objection even to very hard waters. Nitrites in peat or rain waters, in tap waters from galvanized pipes, or in waters from freshly cemented reservoirs so long as caustic alkalinity is present, are unobjectionable. Water freed from iron in closed pressure-type filters contains traces of nitrites because of incomplete oxidation of ammonia compounds present.—*Mans.* Translated by Selma Gottlieb.

Equilibria in the Reaction of Sodium Carbonate, Sodium Hydroxide, Calcium Hydroxide and Tri-Sodium Phosphate with Calcium and Magnesium Sulfates. J. LEICK. Ztschrift. f. anorg. u. allgemein. Chem., 210: 2, 203, January, 1933. Calcium carbonate has solubility of 0.75 milli-equivalents per liter in carbon-dioxide-free water at $100^{\circ}\text{C}.$ This is increased by sodium chloride and still more by sodium sulfate. Under same conditions, magnesium carbonate has an apparent solubility of 1.5 milli-equivalents, dissolving partly as carbonate and partly as bicarbonate; but as on longer boiling it is completely converted into magnesium hydroxide, the solubility of the carbonate at 100° is fallacious.

In reaction of a solution of calcium chloride and sulfate with equivalent amount of sodium carbonate, attainment of equilibrium is practically complete in two hours at lower temperatures and in one hour at higher ones. At low concentrations, residual content of calcium is greater and attainment of equilibrium is slower. Sodium carbonate excess of 1.5 to 2.0 milli-equivalents is best, since larger quantities cause no essential change. Reaction between magnesium sulfate and sodium hydroxide is quite complete and is scarcely influenced by excess of carbonate. Presence of magnesium sulfate, even in small quantities, retards reaction between calcium sulfate and sodium carbonate and causes greater residual calcium content, which is less reduced by excess carbonate than in case of pure calcium sulfate. Reaction between magnesium sulfate and sodium, or calcium, hydroxide depends little on temperature, time, or concentration; with an excess of 0.5 to 1.0 milli-equivalent, residual magnesium content of 0.15 to 0.20 milli-equivalent is attained. Reaction of calcium chloride with tri-sodium phosphate goes further than that with sodium carbonate; at 70° only 0.25 milli-equivalent remains in solution. The precipitate is not pure tri-calcium phosphate, but contains excess calcium; the phosphate content, however, increasing with temperature, time, and concentration. At low concentrations, more phosphate remains in filtrate. Attainment of equilibrium is practically complete after 15 minutes. With excess of 0.5 to 1.0 milli-equivalent at 20°, residual calcium content is 0.15 to 0.20 milli-equivalent; at 80°, 0.1 milli-equivalent.—*Manz. Translated by Selma Gottlieb.*

Water Purification in the Modern Brewery and Distillery. F. J. LAMMERS. *Ind. Eng. Chem.*, 26: 1133-8, November 1934. Brewing water must be clear, tasteless, and odorless. Alkalinity is undesirable and is usually reduced by lime treatment, followed by adjustment to about pH 7.0 with lactic or phosphoric acid. Iron is very objectionable and must be removed. Presence of some calcium sulfate and sodium chloride is desirable, especially in fermentation and clarification; but excess of these or of other minerals is undesirable. Not more than 300 p.p.m. of any one substance should be present and not more than 800 p.p.m. of total solids. Water should meet standard bacteriological requirements for drinking water. Inert organic matter in small amounts is unobjectionable, but an excess must be removed. Washing and rinsing water must be of good sanitary quality and free from iron and from excessive hardness. Usual requirements for boiler feed water and cooling water must be met. Distillery water should meet the combined requirements of brewing, boiler feed, and cooling water, as above. Distilled water used for blending must be free from objectionable volatile contaminants; undistilled water, if of satisfactory mineral quality, is preferable. Water treatment methods for breweries and distilleries follow lines of current municipal practice.—*Selma Gottlieb.*

Ionic Silver Sterilization. C. H. BRANDES. *Ind. Eng. Chem.*, 26: 962-4, September, 1934. Required concentrations are as low as 0.05 p.p.m. for drinking water sterilization and range up to 0.9 p.p.m. for sterilization by washing. Equipment consists of silver plates from which silver is driven into water by applied electromotive force. Required contact period with silver ions depends

on turbidity, composition, and pH of water, and ranges from one hour up, using 0.05 p.p.m. of silver. For some other liquids, silver dispersed on an inert medium is preferable. Applications to pool water and to alcoholic and other liquids are discussed.—*Selma Gottlieb.*

Journal of the New England Water Works Association, 48, 1, March 1934.
A Ten-Foot Parshall Measuring Flume at Providence, R. I. CHAS. G. RICHARDSON. 1-5. Flume used for metering at sewage disposal plant may prove equally applicable for measuring flow of water under similar conditions, namely, where weirs or large Venturi tube would involve costly excavation, etc. Idea of open, Venturi-shaped flume with converging inlet, straight throat, and diverging outlet with level floor, originated with V. M. CONE, of Colorado Agriculture College, in 1915; but it was apparently impossible to establish definite, dependable relation between difference in head at inlet and throat and rate of flow. R. L. PARSHALL devised important alterations in angles of convergence and divergence and in side slopes, to give greater stability of water surface. By adding a dip in floor beyond throat section, hydraulic jump was provided, which eliminated throat gage for majority of installations, flow being read as single gage height in inlet cone. Flumes are in wide use in western irrigation districts, with throat widths of from 1 to 40 feet and corresponding maximum capacities of 0.5 to 2,600 second-feet. Providence flume has throat width of 10 feet. Recording instrument in use is Builders Iron Foundry Type Y specifically modified Register-Indicator-Recorder, operated by 24-inch diameter float in concrete well connected to both flume vents. Graduation range is from 10 to 130 m.g.d.; corresponding float travel, 0.5 to 2.7 feet. **Modern Water Chlorination Practice.** L. H. ENSLOW. 6-22. Since inception in Belgium in 1902, chlorination theory and practice have undergone considerable changes. Chlorine was at first applied to raw water; then, instead, to filtered water. More recently, it is again being applied to raw, or to coagulated water, to obtain desired effects other than mere disinfection. Important landmark was practical application of *ortho*-tolidine test about 1918-9, which insures adequate disinfection without over-chlorination. Taste production directly attributable to reaction of chlorine with foreign matter has introduced new problems. While super- and de-chlorination and permanganate treatment in conjunction with pre-chlorination have proved effective, neither has come into such popular use as ammonia-chlorine. Ammoniation has two important purposes: (1) to prevent objectionable tastes resulting from chlorination and (2) to create persistent form of available residual chlorine which keeps down dead-end complaints, reducing necessity for flushing, controls *Crenothrix*, and suppresses biologically induced tuberculation in distant fringes of distribution system. Lower oxidation potential of chloramine necessitates higher residual, with longer contact period, to insure sterile water. Where no risk of undesirable chloro-products is incurred, chlorine may be applied first to disinfect water, and then just enough ammonia to combine with residual chlorine present. Activated carbon applied to raw or coagulated water, following a mild super-chlorination, is most universally successful procedure in taste control. When carbon is finally laid down on filter bed, it completely dechlorinates water, simultaneously adsorbing and

removing taste-producing chloro-products. **Recent Additions to the Cambridge, Mass., Water Supply.** HOWARD M. TURNER. 28-46. Combination of large drainage area, 16.5 square miles, with relatively small capacity, 402 m.g., at Stony Brook, the center of 3 interconnected storage reservoirs, caused loss of 7.4 m.g.d. and consequent water scarcity. Prohibitive cost of joining Metropolitan System suggested greater utilization of Stony Brook catchment area by lowering existing limit of draft at Fresh Pond from 9 to 30 feet. Additional 1.9 m.g.d. brings dry year minimum to 14.9. New pumping station was installed at Fresh Pond, and 6 additional rapid sand filters increased output of plant to 18 m.g.d. average. While problem of adequate water supply has been temporarily solved, potential source in Spencer, Tophet, and Nashoba brooks is under investigation. **Corrosion of Brass in Water Subjected to pH Correction.** EDWARD W. MOORE. 47-58. Recent tendency to minimize corrosion of water systems in which ferrous metals predominate, by increasing pH of water, has led PIRNIE and others to point out that with pH too high, zinc, alum, tin, and lead may dissolve. Experiments to determine effect of water at pH values varying from 6.0 to 11.0 on zinc in brass pipe (of 60 percent copper to 40 percent zinc) were conducted at Harvard. Cambridge water, normally of pH 8.0, was adjusted with hydrochloric acid, or sodium carbonate, to desired pH values, which were maintained. Uniform sections of pipe with 20 square inches of exposed surface were placed with the water in jars for 60 and 120 days at 25°C. Jars were shaken to re-aerate water and insure uniform oxygen concentration. Results were: (1) Dezincification of brass appears to decline from pH 6.0 to a minimum at pH 10.0, and then to rise slightly to pH 11.0; (2) Solution of copper from brass appears to be related inversely to that of zinc, minimum figure for zinc coinciding with maximum for copper; and (3) Protective films retard dezincification only in limited range, from about pH 7.5 to 9.5. Most striking result was variation in range of zinc dissolved in 120 day test, from 215 mg. at pH 6.0 to 1.4 mg. at pH 10.0. **A History of Water Service Installation in Newton, Mass.** MICHAEL J. HERLIHY. 59-65. System has grown from 496 services in 1876 to over 15,000. Leaks occurring in average year represent 0.64 percent of total services in use. This figure will be materially reduced as lead gooseneck connection between tap and service pipe, and 1" galvanized nipples at corporation and curb cocks are replaced. The proportion of rigid connections, now 40 percent, will increase with normal growth. **Water Works Practice at Taunton, Mass.** ARTHUR C. KING. 66-71. Taunton uses but 3 m.g.d. of its legal allotment of 8 m.g.d. Water is used untreated, and reservoirs and water shed are not patrolled; dependence for purity being placed on long storage. Pumping units are in duplicate, with provision for increasing pressure from 70 to 110 pounds in case of fire. Constant inspection of distribution system, with flushing of hydrants on dead ends, reduces complaints. Frozen hydrants are thawed by dropping in lump carbide which eats hole through in few minutes. **Results of Water Waste Survey in Lexington, Mass.** A. A. ROSS. 72-75. Investigation in fall of 1931 disclosed but 53½ percent of total water consumption, as recorded by Boston Metropolitan Water District Commission's meter, accounted for. Pitometer survey at cost of \$2,831 disclosed leakage in standpipe of 3,000 g.p.d. and 5 major underground leaks totaling 145,000 g.p.d. Leaks caused loss of \$3,456 annually. A

Résumé of Changes in Practice and Recent Improvements in Water Supply at Newton, Mass. RICHARD H. ELLIS. 76-87. Preliminary survey of existing conditions led to ambitious program to increase general efficiency. Remodeled shop building provided adequate space for five-year inspection on all meters. System for meter records was installed, and reading and billing procedure revised. Quality of water was improved as result of experiments on corrosion control, dead ends were eliminated, and physical plants and appurtenances, from infiltration bowls to distribution system, rebuilt, extended, or replaced. Work outlined in following articles, involving total expenditure of \$468,000, was paid for largely from current revenue, only \$200,000 being raised on bonds for extension purposes. This city of 70,000 has now an adequate supply (6 m.g.d.) without purchasing from the Metropolitan District; shows an annual surplus of \$170,000, as against a deficit of \$23,600 in 1929; and has reduced rate base from 25 to 20 cents per 100 cubic feet. **Engineering Problems Connected with Recent Improvements to the Newton, Mass., Water Supplying Works.** GEORGE A. SAMPSON. 88-101. Water supply is obtained from unusual gravel deposit along Charles River. When in 1926 two infiltration conduits which supplied 1 m.g.d. of total available yield of 3.75 m.g.d. were abandoned, because of flood water contamination, the condition became serious. Considerable water was being purchased from the Metropolitan District Commission to augment supply from dug well No. 1 and 4 by 4 ft. wooden infiltration conduit. Dug well No. 2 when completed was found inadequate; so flooding development was started, to augment ground water supply. After area was cleared and stripped to gravel, pump was installed at river, and flooding begun. Lateral distance of 150 feet from flooding basin or bowl to point of collection was adequate to insure complete sterilization. Total yield increased to 6 m.g.d. with certainty that source could be developed to full legal limit of 8 m.g.d. New steam turbine driven pumps with generators were installed at pumping station. Present capacities of 4, 6, and 8 m.g.d. may be increased by changing impellers to 5, 7, and 9, respectively. Cost of coal is \$1.37 per m.g. per 100 feet. Cost of generating electric power is 0.415 cents per k.w.hr. at switchboard. **Boiler Plant Needham Street Pumping Station.** DAVID EAMES. 102-104. Capacity of Newton, Mass., boiler plant was determined by reference to steam demand of turbine driving largest (8 m.g.d.) pump, with full electrical load on generator in addition. Each boiler has capacity for entire load so that second is always in reserve. At full steam pressure, evaporating 10,000 pounds per hour, boiler will operate at 135 percent of rated capacity. Water tube boilers are of cross drum, straight tube type, with 2,500 square feet of heating surface. Operating steam pressure is 240 pounds per square inch and steam temperature, 550°F. Pulverized coal gives higher efficiency, as indicated by high CO₂, low exit-gas temperature, and clean stack, at a saving of \$1,400 annually. **Experiments on the Newton, Mass., Water and Treatments for the Control of Corrosion.** F. WELLINGTON GILCREAS. 105-116. Carefully set up experiment showed that untreated ground water supply collected from Charles River had decided initial action on wrought iron pipe, which dropped off after some weeks. With galvanized iron and brass pipe, solution of zinc continued throughout experiment. It was decided to increase pH from 6.2 to 7.8 by addition of soda ash. Change was made in

gradual steps over six-month period, with no resulting complaints of dirty water, indicating that increase in alkalinity did not disturb deposits already existing. When pH increased to above 7.2, complaints of green stains, due to action of water on copper, ceased. Carbon dioxide is reduced from between 25 and 30 to 4.0 p.p.m. Soda ash added, 400 pounds per m.g. at 1½ cents per pound, costs \$5.00 per m.g., or \$10,000 per year.—*T. F. Donahue.*

Research Has Contributed to Locomotive Fuel Economy. J. R. JACKSON et al. *Railway Age*, 97: 14, 399-400, 1934. Committee on locomotive economy devices reported to International Railway Fuel Association that water treatment and systematic blow-down schedules have effected appreciable economies in locomotive maintenance and utilization. Mandatory blow-down schedules are recommended, checked by terminal concentration tests. Signal foam meter and electromatic blow-off have proved serviceable.—*R. C. Bardwell (Courtesy Chem. Abst.).*

Money Spent for Better Water Brings Large Return. Anon. *Railway Age*, 97: 18, 534-536, 1934. Total scale-forming matter in waters taken at 52 stations on Chicago and Eastern Illinois RR. varies from 1.8 to 51.0 grains per gallon, of which non-carbonate hardness will vary from a trace to 25.4 grains. In 1931, treatment was started with sodium aluminate and other chemicals to neutralize the non-carbonate hardness at all roadside tanks and maintain a desired soda alkalinity in the boilers. Cost records presented show large resulting economies in boiler maintenance.—*R. C. Bardwell (Courtesy Chem. Abst.).*

Water Consumption and Metering in Philadelphia. Bureau of Municipal Research of Philadelphia, December, 1933. A 32-page report on Bureau's inquiry. Water services are now about 43 percent metered. Total output in 1927 was 125,983,400,000 gallons; in 1932, 111,337,500,000 gallons. Water taken through meters in 1927 was 45,946,700,000 gallons; of remainder, it is estimated that municipal requirements would account for about 19 billion gallons, and losses in distribution system for about 16 billion and that 45 billion passed through unmetered services. Bureau's analysis indicates that 18 billion gallons would have been saved if these services had been metered. Per capita consumption would have been reduced 14 per cent and saving of \$180,000 effected on operation and maintenance.—*R. H. Oppermann.*

An Examination of Water from Various Natural Sources for Variations in Isotopic Composition. E. W. WASHBURN and E. R. SMITH. *Bureau of Standards Journal of Research*, 12: 3, 305-311, March, 1934. Reviews a differential synchronometer method of measuring small differences in density, previously described in same journal (11: 453, 1933). Water tested included that prepared from milk, blood, etc. Small differences have been found after removal of all non-aqueous constituents. The water of the ocean, Dead Sea, and of Great Salt Lake is denser than pure normal water by about 2, and the water of crystallization of native borax tetrahydrate, kernite, by about 7, parts per million.—*R. H. Oppermann.*

The Heightening of the Assouan Dam. Engineering, 137: 559-561, May 18, 1934. Describes the second heightening of dam built across River Nile, 753 miles from sea, for summer water supply. As built in 1902, it was 1960 meters long and 39 meters from top to deepest foundation and contained 583,000 cubic meters of masonry. In 1907, crest was raised to 44 meters and length increased to 1982 meters. Height has now been further increased by 9 meters.—*R. H. Oppermann.*

Thawing Frozen Water Pipes by Heating With Arc Welding Generators. S. C. OSBORNE. Steel, 96: 3, 31-32, January 21, 1935. Since electric current flow through pipe generates heat in pipe itself, this method of thawing is most economical. Current capacity of generator must not be exceeded for any extended period of time. Section of pipe taken should be so long that terminal voltage of machine is approximately at its rating. Table, compiled on assumption that pipe is frozen solid and is free of air and that approximately half of heat developed is lost from outside of pipe to air, shows current needed to melt ice completely in 1 hour. For iron or steel pipe from $\frac{1}{4}$ -inch to 2-inch, from 30 to 170 amperes are required. Values for brass and copper pipe are also given.—*R. H. Oppermann.*

A Glass Electrode Potentiometer System for the Determination of the pH Values of Weakly Buffered Solutions Such as Natural and Treated Waters. J. O. BURTON, HARRY MATHESON, and S. F. ACREE. Bureau of Standards Jnl. Research, 12: 1, 67-73, January, 1934. In the electrometric measurement of the pH values of buffered solutions more dilute than M/10,000 by means of quinhydrone and hydrogen electrodes, resistance of the solution, escape of carbon dioxide, acid properties of quinhydrone, and polarization of the electrodes are so disturbing that e.m. f. readings may vary by as much as from 5 to 30 millivolts, or from 0.1 to 0.5 pH unit. The isohydric-indicator technique is apparently applicable within 0.1 pH to such solutions and to distilled water, but has not heretofore been compared with a reliable e.m.f. method. By adding VARLEY shunts to a modification of the vacuum-tube potentiometer used by PARTRIDGE, keeping the grid attached to the circuit, and using a THOMPSON glass electrode, e.m.f. readings can be made within 0.1 to 2.0 millivolts on weakly-buffered solutions and on distilled water, pH values thus obtained agreeing with those by isohydric-indicator method. This apparatus is also suitable for measuring the pH of solutions containing active oxidizing or reducing agents, such as chlorine, or tannins, where the hydrogen and quinhydrone electrodes and indicator methods might fail.—*R. H. Oppermann.*

The Law of Flow Through Disc-Orifices in Pipe Lines. A. A. BARNES. Engineering, 137: 25, January 5, 1934. Good review of paper presented before Institution of Water Engineers, London, December 1, 1933. Earlier work with orifice method of measurement having been confined chiefly to small pipes and small amounts of water, tests were conducted with pipe line of 60-inch diameter, passing 32,000,000 gallons per day, which was laid in parallel with two cast-iron mains of 42-inch diameter, so that it was possible, by cutting off the new main, to measure frictional losses when passing the same quantities of

water. Orifice used was 36 inches in diameter and pipe, 2571 feet long, was concrete lined. Relationship of gross drop in head at orifice to head regained downstream therefrom was found to be: head regained = $0.328 \times$ gross drop at orifice. Frictional loss values in pipe were related as follows to drop at orifice and to regained head; : orifice drop = $3.354 \times$ (frictional loss in feet)^{1.145}; regained head = $1.1 \times$ (frictional loss in feet)^{1.145}.—*R. H. Oppermann.*

Algal Growths and Water Supply. J. W. HUSBAND. Engineering, 137: 26, January 5, 1934. Review of paper presented before Institution of Water Engineers, London, December 1, 1933. Copper sulphate does not always provide satisfactory solution of algal difficulties in reservoirs. Three concrete-lined reservoirs of the Bedford, England, Corporation are supplied from (a) a 60-foot well of hard water, free from algae and (b) a river, whose water contains a variable quantity of algal spores and debris with fine mineral silt. Disinfection with chlorine removes harmful bacteria, but other undesirable forms persist. Copper sulphate as algicide gave no lasting relief and taste troubles resulted. Diatoms and algal debris were found to have penetrated filter bed, only about 30 percent of fine suspended matter having been deposited in the 3 to 4 days passage through reservoirs. Potassium permanganate applied to raw water has improved palatability and demand of reservoirs for frequent cleaning has disappeared.—*R. H. Oppermann.*

NEW BOOKS

Selected Papers, Proceedings of the Ninth Annual Conference on Water Purification, 1933. Technical Bulletin No. 7, West Virginia University, Morgantown, W. Va. 6 x 9 inches. 89 pp. **Under What Conditions Will the Flow of Electric Current Cause Corrosion?** C. E. TROWBRIDGE. 5-12. An instance of badly discolored water in a distribution system under unusual conditions was believed to be due to a constantly reversing current, which prevented the polarization that would ordinarily arrest corrosion by formation of protective coating. **Nitrifying Bacteria in Water Supplies.** DOUGLAS FEBEN. 13-23. Studies at Detroit indicate that pre-ammoniation supports growth in filter beds of nitrifying bacteria, which in turn produce high chlorine demand, thus resulting in waste, both of ammonia and of chlorine. Methods of isolation and culture of organisms are given. **Control of Tastes and Odors in Public Water Supplies.** M. E. FLENTJE. 24-30. Progress in elimination of tastes and odors will depend upon actual determination of some of the compounds causing these objectionable qualities; upon development of better laboratory methods of determination; and upon continued study of the problem, utilizing these developments. **Recent Improvements in the Wheeling Water System.** A. R. TODD. 31-34. Product has been improved by changes in operating methods, involving adjustment of pH, and use of ammonia and of activated carbon and, when raw water is acid, of soda ash. **The Present Trend of Public Utility Rates and Financing.** J. H. MURDOCK, Jr. 35-41. Rendering of public utility service by a government unit is not a government function, but a business enterprise, and should be subject to taxation

and to other obligations imposed upon private companies. **The Registration of Water Plant from the Operators' Viewpoint.** PERKINS BOYNTON. 42-45. Training, examination, and registration of operators has resulted in increased efficiency in operation and in development of keen interest of the men in their work. **Laboratory Control.** L. V. CARPENTER and G. R. PYLE. 46-51. Laboratory methods for determination of acidity and calculation of chemical dosages for treatment of acid waters. **Studies of Morgantown Water Supplies, Especially Their Variations in Mineral Content.** W. W. HODGE and R. NEWTON. 52-69. Cheat River, Tibbs Run, deep wells, and Monongahela River were investigated and a combined supply developed from Tibbs Run and Monongahela River. Seasonal variations in quality of each source are reported in detail. **Effects of Road Oils and Tars on Public Water Supplies.** L. V. CARPENTER, E. W. KLINGER, and G. R. PYLE. 70-83. Cooperative tests by W. Va. University, State Road Commission, and State Water Commission indicate that asphalt road washings do not produce tastes, but that tar road washings do; in consequence of which, road tars with low phenol contents should be selected. **Short Time Duration Rainfall Intensities Recorded at Mechanical Hall, Morgantown, W. Va., 1924-1933.** 84-86. **Registration, W. Va. Conference on Water Purification.** 87-89.—R. L. McNamee.

Journal of the Southeastern Section, A. W. W. A., 4: 1, 5-96 pp., 1934. **Reconstruction of the Riverside Station at Macon, Ga.** T. E. P. WOODWARD. 5-15. Description of new pumping and water treatment units. **Handling and Storing Water Works Chemicals.** L. L. HEDGEPEETH. 16-30. Physical properties of ammonia, of aluminum sulfate, and of activated carbon are described. Precautions observable in storing and handling ammonia containers are given. Activated carbon must not be mixed with quicklime, or with dry hypochlorite, lest spontaneous combustion result. First aid measures applicable in event of ammonia accidents are described. Curves showing (a) volume and pressure changes due to temperature for liquid ammonia and (b) pressure and ammonia percentage relationships to temperature for aqua ammonia are included. **The Flow of Small Streams.** B. M. HALL, Jr. 31-43. Volume of flow in small streams not ordinarily gaged by United States Geological Survey is of great importance to water works men. Author describes and explains various methods applicable to small stream measurement. Stream flow records to be of real value need not be of extreme accuracy, but continuity of record is of vital importance. Further cooperation with Federal Government by municipalities and states is greatly needed. Water works men can aid greatly in educating the public as to need and value of stream gaging. **Putting Plan into our Future.** H. T. McINTOSH. 44-50. Plea for conservation of natural resources through careful long-range national and local planning. **Underground Corrosion in the Southeastern United States.** K. H. LOGAN. 51-71. There are in the United States approximately 450,000 miles of pipe underground, valued at nearly one billion dollars. Corrosion losses on this property probably exceed \$100,000,000 annually. Chief cause of differences in electrical potential which cause localized corrosion lies, not in impurities or strains in buried metal, but in differences in supply of oxygen at different areas of metal's surface. Uncontrolled and unrecognized conditions modify rates

of underground corrosion to such an extent that two pieces of same material in same soil may corrode quite differently. **Trends in Stream Pollution Research and Control.** J. K. Hoskins. 72-83. Review of some of more important developments in field of stream sanitation in the United States. Present tendency is for administrative control of stream pollution to rest with the individual states, with Federal assistance and cooperation. Interstate agreements such as formal treaties, or less formal cooperative arrangements, entered into by state administrative officers, are significant. **Methods of Sewage Treatment, Their Object and Utility.** M. T. Singleton. 84-96. Description of biological and chemical treatment methods, with reference to their application to various conditions.—W. H. Weir.

Finding Work. SAMUEL S. BOARD. Reprint—Am. Soc. Mech. Eng. 29 W. 39th Street, New York, N. Y. Price 10 cents. At the recommendation of its Council, the American Society of Mechanical Engineers had this pamphlet prepared by a placement specialist to deal in a practical way with the important problem of finding work. No claim is made for originality in connection with the suggestions given. They involve a restatement of the whole process which must be followed in finding work when it isn't easily available. The subject is discussed under the following headings: distinguishing factors in the engineer's problem; what the engineer has to offer; importance of appearance; making a personal appraisal; types of work open to engineers; getting things done; research; the consulting engineer; sales engineering; engineers in business; planning a job campaign; where to look for a job; the salary question; closing the deal; looking ahead while working, and professional advancement.—A. W. Blohm.

Numerals in Colors for Multiple-Point Recording. Circular 314-I Leeds & Northrup Co., Philadelphia. Reading of multiple-point instrument records is simplified by a new system of "numerals in colors." This system can be specified on Micromax strip-chart recorders for 2, 3, 4 or 6 points. With each thermocouple, resistance thermometer bulb, or other primary element, identified on the chart by a numeral and each numeral distinguished by being printed in a contrasting color, reading of records is made easy, errors are avoided and time is saved.—A. W. Blohm.